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PLASTIC PIPING HANDBOOK

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CHAPTER 1
GENERAL INFORMATION

INTRODUCTION

The purpose of this handbook is to provide accurate and reliable information concerning the application, design, and installation of plastic pipe for water and gas systems.

Thermoplastic piping is the material that has the widest range of applications. Thermoplastic piping includes many materials that have significant differences in characteristics and uses. It is important that the correct thermoplastic material be specified for the various applications. Because of the frequent use of polyethylene (PE) and polyvinyl chloride (PVC) pipe material in the water and gas markets, this handbook will focus primarily on these types of plastic pipe. Other types of plastic pipe and their applications will be introduced to provide the reader with a background in the various possible uses of the material. The design and installation information, however, will deal primarily with PE and PVC pipe.

Each project is different and can have unique conditions. A design or installation necessity for one project might be excessive for another project. The ways the engineer and designer interpret and approach the various conditions are important to achieve an effective and efficient project. The proper design and installation of plastic piping systems require the use of sound engineering judgment and principles. It is the goal of this handbook to provide the information needed by designers, engineers, and installation personnel working in the water and gas fields.

Plastic piping has many applications in today's marketplace and its popularity continues to grow. It is used in a variety of commodities such as acid solutions, chemicals, corrosive gases, corrosive waste, crude oil, drainage, fuel gases, mud, sewage, sludge, slurries, and water. One major reason for the growth in the use of plastic pipe is the cost savings in installation, labor, and equipment as compared

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to traditional piping materials. Add to this the potential for lower maintenance costs and increased service life and plastic pipe is a very competitive product. The popularity of plastic pipe in the water and natural gas industry has played a significant role in the growth of the industry. The shipment of PE products alone increased by 26 percent from 1996 to 1997 [1].

HISTORY OF PLASTIC PIPE MATERIALS

Plastics have been in use for more than 100 years, and polyethylene, the primary plastic pipe used in the natural gas industry, was invented in the 1930s. Early polyethylenes were low density and were used primarily for cable coatings. World War II provided a catalyst for the development and use of plastic products, largely because of the shortage of other materials. Today's modern polyethylene piping systems began with the discovery of high-density polyethylene in the early 1950s [2].

COMMON APPLICATIONS

Thermoplastics make up the majority of plastic pipe in use today. PVC accounts for the majority of the thermoplastic pipe in use, with PE coming in second. Although thousands of miles of plastic pipe are in service in natural gas and municipal applications, many other uses also exist. Some of the other common uses of plastic piping are:

Chemical processing
Food processing
Power plants
Sewage treatment
Water treatment
Plumbing
Home fire and lawn sprinkler systems
Irrigation piping

Detailed information about various piping products and their applications can be obtained from the Plastic Pipe Institute and plastic pipe manufacturers.

In the last 25 to 30 years, plastic piping products have become the predominant piping materials in many markets. As a result of the high demand, the availability and types of plastic piping products in many materials and sizes have increased significantly. This increase provides the piping engineer with many products to choose from when specifying plastic piping products. To select the best product for the desired application, the engineer and designer must have a good knowledge of the plastic piping products available.

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DEFINITIONS AND ABBREVIATIONS

adhesive joint: A joint in plastic pipe made by an adhesive substance that forms a continuous bond between the materials without dissolving either of them.
ambient temperature: The prevailing temperature in the surrounding medium usually refers to the temperature of the air surrounding an object.
anchor: A rigid device used to secure the pipe, permitting neither translatory nor rotational displacement of the pipe.
angle of bend: The angle between the radial lines from the beginning and end of the bend to the center.
backfill: The material that is placed around and over the pipe after trench excavation.

primary initial backfill: This part of the backfill supports the pipe against lateral pipe deformation.

secondary initial backfill: This part of the backfill distributes overhead loads and isolates the pipe from any adverse conditions encountered during the placement of the final backfill.

final backfill: The final material inserted in the trench to complete the fill from the initial backfill to the top of the trench.
ball valve: A valve with a ball-shaped disk that has a hole through the center, providing straight-through flow.
blind flange: A flange used to close the end of a pipe.
block valve: A valve used for isolating equipment.
burst pressure: The pressure that can be applied slowly to plastic pipe or component at room temperature for 30 seconds without causing rupture.
burst strength: The internal pressure required to break a pipe or fitting. This pressure will vary with the rate of buildup and the time the pressure is maintained.
butt fusion: A method of joining thermoplastic pipes and components that involves heating the ends of two pieces that are to be joined and quickly pressing them together.
butt joint: A joint between two pipe components in the same plane.
butterfly valve: A valve that gets its name from the wing-like action of the disk.
bypass valve: A valve and loop used to direct the flow in a pipeline around some part of the system.
check valve: A device that allows flow in one direction only in a pipeline.
coefficient of expansion: The increase in unit length, area, or volume for a unit rise in temperature.
compression fitting: A fitting used to join a pipe by pressure or friction.
compression joint: Multi-piece joints with cup-shaped threaded nuts that compress sleeves when tightened so they form a tight joint.
compression strength: The failure crushing load of a pipe or component divided by the number of square inches of resisting area.
control piping: All piping, fittings, and valves used to connect control devices to the piping system components.

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creep: Time-dependent strain caused by stress. Creep is a dimensional change with respect to time caused by a load over the elastic deformation.
density: The mass of a substance per unit volume.
depth of fusion: The distance that a fusion extends into the base material.
deterioration: The permanent adverse change in the physical properties of a plastic.
dimension ratio: The diameter of a pipe divided by the wall thickness.
elasticity: The material property that tends to retain or restore the materials original shape after deformation.
elastomer: A material that, under ambient conditions, can be stretched and returns to approximately the original size and shape after the applied stress is released.
elevated temperature testing: Test on plastic pipe above 73°F.
environmental stress cracking: Cracks that develop when the material is subjected to stress in the company of certain chemicals.
expansion joint: A piping component used to absorb thermal movement.
expansion loop: A bend in a pipe run that adds flexibility to the piping system.
flexural strength: The pressure (psi) required to break a piping sample when the pressure is applied at the center and the pipe is supported at both ends.
full port valve: A valve that, when in the fully open position, is equal to an equivalent length of pipe.
gate valve: A valve that opens to the complete cross section of the line. Under most conditions, a gate valve is not used for throttling or control of the flow. It usually is used for complete open or complete shutoff of the fluid flow.
globe valve: A valve used for throttling or control.
haunching: The area from the trench bed to the spring line of the pipe. Provides most of the load bearing for buried piping.
heat joining: The making of a pipe joint in thermoplastic piping by heating the ends of both sections so they fuse when the parts are pressed together.
incomplete fusion: A fusion that is not complete and does not result in complete melting throughout the thickness of the joint.
joint: A connection between two sections of pipe or between a section of pipe and a fitting.
long-term burst: The internal pressure at which a pipe or fitting will fail due to constant internal pressure held for 100,000 hr.
nominal Pipe Size (NPS): A dimensionless designator of pipe size. It indicates standard pipe size when followed by the specific size designation number without an inch symbol (e.g., NPS 2, NPS 10) [3].
non-rigid plastic: A plastic whose modulus of elasticity is not greater than 10,000 psi in accordance with the American Society of Testing and Materials (ASTM) Standard Method of Test for Stiffness in Flexure of Plastics.
pipe alignment guide: A piping restraint that allows the pipe to move freely in the axial direction only [4].
pipe stiffness: A measure of how flexible pipe will be under buried conditions.
pipe supports: Components that transfer the load from the pipe to the support structure or equipment.

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plastic: A material that contains an organic substance of high to ultra-high molecular weight, is solid in its finished state, and at some stage of its processing can be shaped by flow.
plastic, semi-rigid: A plastic whose modulus of elasticity is in the range of 10,000-100,000 psi in accordance with the Standard Method of Test for Stiffness in Flexure of Plastics.
plug valve: A valve that consists of a rotating plug in a cylindrical housing with an opening running through the plug.
pressure rating: The maximum pressure that can be inserted in the pipe without causing failure.
reinforced plastic: According to American Society for Testing and Materials, plastics having superior properties as compared to plastics consisting of base resin because of the presence of high-strength filler material embedded in the composition.
relief valve: A safety valve for the automatic release of pressure at a set pressure.
standard dimension ratio (SDR): A series of numbers in which the dimension ratio is constant for all sizes of pipe.
stiffness factor: A property of plastic pipe that indicates the flexibility of the pipe under external loads.
sustained pressure test: A constant internal pressure test for 1,000 hours.
thermoplastic: A plastic that can be softened repeatedly by heating and hardened by cooling. During the soft state, it can be shaped by molding or extrusion.
thermosetting: A plastic that is capable of being changed into an infusible or insoluble product when cured by heat or chemical means.
yield stress: The force required to initiate flow in a plastic.
Young's modulus of elasticity: The ratio of stress in a material under deformation.

ACRONYMS AND ABBREVIATIONS

ASME	American Society of Mechanical Engineers
ANSI	American National Standards Institute
API	American Petroleum Institute
ASCE	American Society of Civil Engineers
ASPOE	American Society of Petroleum Operations Engineers
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BBL	Barrel = 42 U.S. gallons
BTU	British thermal unit
CAD	Computer-aided design
FRP	Fiberglass-reinforced plastics
GPM	Gallon per minute
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
MDPE	Medium-density polyethylene

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PB	Polybutylene
PE	Polyethylene
PJA	Pipe Jacking Association
PP	Polypropylene
PPFA	Plastic Pipe Fitting Association
PPI	Plastic Pipe Institute
PRI	Plastic and Rubber Institute
PVC	Polyvinyl chloride
VMA	Valve Manufacturers Association

PLASTIC PIPING CODES AND STANDARDS

Codes

Codes establish the minimum requirements for design, fabrication, materials, installation, inspection, and testing for most piping systems. Thermoplastics used for plumbing, sewer, water, gas distribution, and hazardous waste may come under the jurisdiction of a code or regulation. Some of the most frequently used codes for plastic piping products used for water and gas applications are:

BOCA National Mechanical Code

BOCA National Plumbing Code

ASME B31.3 Chemical Plant and Petroleum Refinery Piping

ASME 31.8 Gas Transmission and Distribution Piping Systems

ANSI Z223 National Fuel Gas Code

Code of Federal Regulations (CFR), Title 49, Part 192, Transportation of Natural Gas and other Gas by Pipeline

Code of Federal Regulations (CFR), Title 49, Part 195, Transportation of Liquids by Pipeline

NFPA 54, National Fuel Gas Code

Standards

Standards provide rules that apply to individual piping components and practices. The American Society for Testing and Materials establishes the majority of the standards used in the manufacture of plastic piping products. ASTM develops and publishes voluntary standards concerning the characteristics and performance of materials, products, and services. ASTM standards include test procedures for determining or verifying characteristics such as chemical composition, and measuring performance such as tensile strength. Committees drawn from professional, indus-

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trial, and commercial interests develop the standards, many of which are made mandatory by incorporation in applicable codes. Table 1.1 lists the principle ASTM standards that apply to thermoplastic piping products used in water and gas applications.

TABLE 1.1 ASTM Standards for Plastic Piping

	Specifications for
D1600	Abbreviations of terms
F412	Definitions for plastic piping systems
D2749	Symbols for dimensions of plastic pipe fittings
D2581	Polybutylene (PB) plastics molding and extrusion materials
D1228	Polyethylene (PE) plastics molding and extrusion materials
D3350	Polyethylene (PE) plastic pipe and fittings material
D1784	Rigid polyvinyl chloride (PVC) compounds
	Polybutylene (PB) plastic pipe and tubing
F809	Large diameter PB plastic pipe
F845	Plastic insert fittings for PB tubing
D2662	PB plastic pipe SDR
D3000	PB plastic pipe SDR based on outside diameter
D2666	PB plastic tubing
	Polyethylene (PE) plastic pipe, tubing, and fittings
D3261	PE butt heat fusion plastic fittings for PE pipe and tubing
F405	Corrugated PE tubing and fittings
F877	Cross-linked PE (PEX) plastic hot and cold water distribution systems
D2609	Plastic insert fittings for PE plastic pipe
F892	PE corrugated pipe with a smooth interior and fittings
F894	PE large diameter profile wall sewer and drain pipe
D3350	PE plastics pipe and fittings materials
D2239	PE plastic pipe SDR based on inside diameter
F714	PE plastic pipe SDR based on outside diameter
D3035	PE plastic pipe SDR based on controlled outside diameter
D2447	PE plastic pipe, Schedules 40 and 80 based on outside diameter
D2737	PE plastic tubing
D2683	Socket type PE fittings for outside diameter-controlled PE pipe and tubing
F905	Qualification of PE saddle fusion joints
F678	PE gas pressure pipe, tubing, and fittings
D2104	PE plastic pipe Schedule 40
F1055	PE electro-fusion fittings
	Polyvinyl chloride (PVC) plastic pipe, tubing, and fittings
F800	Corrugated PVC tubing and compatible fittings
D3915	PVC and related plastic pipe and fitting compounds

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TABLE 1.1 *(continued)* ASTM Standards for Plastic Piping

	Polyvinyl chloride (PVC) plastic pipe, tubing, and fittings
F949	PVC corrugated sewer pipe with a smooth interior and fittings
F679	PVC large diameter plastic gravity sewer pipe and fittings
F794	PVC large diameter ribbed gravity sewer pipe and fittings
D2665	PVC plastic drain, waste, and vent pipe and fittings
D2466	PVC plastic pipe fittings, Schedule 40
D1785	PVC plastic pipe Schedules 40, 80, and 120
D2241	PVC pressure-rated pipe, SDR Series
D2740	PVC plastic tubing
D2729	PVC sewer pipe and fittings
F512	Smooth-wall PVC conduit and fittings for underground installations
D2467	PVC socket-type pipe fittings, Schedule 80
D2464	Threaded PVC plastic pipe fittings, Schedule 80
D2672	PVC plastic pipe, bell end
D3034	PVC plastic sewer pipe and fittings

The American Water Works Association (AWWA) publishes standards for the requirements for pipe and piping components used in water systems. These standards are used for large-diameter piping systems that are not covered by ASME B31, Code for Pressure Piping, or other codes. AWWA standards are incorporated by reference in many codes and by local authorities. Table 1.2 lists the principle AWWA standards that apply to thermoplastic piping products used in water systems.

TABLE 1.2 AWWA Standards for Plastic Piping

C902	PB plastic pipe and tubing for water service
C901	PE plastic pipe and tubing for water service
C906	PE plastic pipe for water distribution and large diameter line pipe
C900	PVC plastic pipe for water distribution
C905	PVC plastic pipe for water distribution

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1. Plastic Pipe Institute (PPI). Annual Statistics for 1997.
2. Chasis, D.A. 1976. *Plastic Piping Systems.* New York: Industrial Press, Inc.
3. ASME. 1989. B31, Code for Pressure Piping, Section B31.8, Gas Transmission and Distribution Piping System. American Society of Mechanical Engineers. New York.
4. Nayyar, M.L. 1992. *Piping Handbook.* New York: McGraw-Hill, Inc.

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CHAPTER 2
PLASTIC PIPING CHARACTERISTICS

ADVANTAGES AND LIMITATIONS OF PLASTIC PIPING

Advantages

Plastic piping materials vary greatly in their characteristics and properties. These differences benefit the consumer in two ways:

1. Through proper design, each plastic raw material can be properly utilized and controlled by ASTM Standards.
2. A competitive market exists within the plastic pipe industry because the characteristics and properties of different plastic materials often overlap in piping applications.

Plastic piping materials are designed and selected to satisfy the requirements of the application for which they are to be used. When used in piping applications, plastic materials must withstand decades of stress. Plastic pipe manufacturers test their products for short-term and long-term use. These tests provide the designer with the information required in the selection of a plastic piping material for a particular application.

Thermoplastic piping products are cost-effective solutions to a variety of piping applications and offer many advantages when compared to traditional metal piping materials. Some of these features, which have spurred the widespread acceptance of plastic piping materials for many applications, are:

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Corrosion resistance: Plastic piping materials are corrosion resistant and have low flow resistance. Plastic piping systems resist most normal household chemicals and many other substances that might enter a sanitary drainage system. The smooth wall of plastic pipe makes the transport of wastes and water more efficient and effective. Thermoplastic piping materials do not rust or corrode, and resist chemical attack from corrosive soils.

Ease of handling: Plastic piping materials are much lighter than most other piping materials and therefore do not require heavy handling equipment. Cutting, joining, and installing plastic piping is far simpler than the same procedures for other materials. At today's labor rates, the increased productivity is vital to the cost of the overall piping system.

Flexibility and toughness: Most thermoplastic piping materials are flexible, which is an important characteristic for underground applications. The pipe can follow natural contours and transitions around obstacles, which reduces the number of fittings required in most piping applications. Because of their excellent flexibility characteristics, plastic piping materials work well in harsh climate conditions.

Variety of joining methods: Many joining methods are available for plastic pipe. It can be threaded, flanged, cemented, heat-fused, and compression-fitted. The many joining methods make plastic pipe adaptable to most field applications.

Excellent hydraulics: Plastic piping materials provide a smooth pipe wall and have low resistance to flow. They also have a high resistance to scale or build-up.

Lower life cycle cost: Plastic pipe has excellent corrosion resistance and provides a system with a long life. This and other cost benefits make plastic pipe an attractive economic choice.

Long life: The service life of any piping material is important. Millions of plastic piping installations have been in service for more than a quarter of a century and still are functioning well. In most conditions, there is no end of life of a plastic piping system.

Standards: Standards have been developed for many plastic piping materials. Regardless of the manufacturer, these standards make sure that plastic piping products have uniform characteristics.

Easy identification: Plastic piping is marked to aid in identification. Manufacturers mark and test their pipes and fittings according to ASTM Standards. This procedure makes it simple for users to properly identify the many types of plastic pipes and fittings that are available.

Limitations

The primary limitations of thermoplastics come from their relatively low strength and stiffness and their sensitivity to high temperature. Because of these limitations,

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thermoplastic piping materials have been used mainly in low-pressure applications with low temperature limits. Even with these restrictions, thermoplastic-piping materials meet the design requirements for a wide range of applications.

THERMOPLASTIC PIPING MATERIALS

Principal Materials

Plastics are compounds made up of resins (polymers) and additives. Additives, which are used to obtain specific effects in the plastic material during fabrication or use, expedite processing, heighten certain properties, provide color, and furnish the needed protection during fabrication and use. Some of the key additives used in thermoplastic piping are heat stabilizers, antioxidants, ultraviolet screens, lubricants, pigments, property modifiers, and fillers. Table 2.1 lists some of the main additives used in plastic piping materials and their purpose.

Plastic pipe and components are available in a variety of materials, designs, and diameters. National standards have been established for many different wall constructions, such as double wall, ribbed, and foamed core. The various designs offer

TABLE 2.1 Common Additives in Plastic Piping Material

Additives	Purpose	Benefit
Antioxidants	Inhibit or retard reactions caused by oxygen or peroxides.	Extends the temperature range and service life.
Colorants	Pigments and dyes used to give color to plastic material.	Provides any desired color.
Coupling agents	Improves the bonding characteristics of plastic materials.	Improves the mechanical and electrical properties of the plastic material.
Fibrous reinforcements	Improves the properties of the resin.	Fibers improve the strength to weight ratio.
Fillers and extenders	Improves the physical and electrical properties of resin. Also reduces the cost of higher priced resins.	Plastic materials can be more economically produced without a loss of quality.
Heat stabilizers	Helps prevent the degradation of plastic materials from heat and light.	Helps plastic materials to be stable and retain their physical properties in excessive heat.
Preservatives	Helps prevent degradation of polymers by microorganisms.	Helps prevent fungi and bacteria attack on plastic materials. Makes the plastic material better suited for underground use.
Ultraviolet stabilizers	Helps retard the degradation from sunlight.	Allows plastic material to be used outdoors without any significant changes of the physical properties.

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materials with different characteristics, strengths, and stiffness. The Plastic Pipe Institute (PPI) publishes a periodically updated report, PPI TR-5, which includes a listing of North American and international standards for thermoplastic piping. In addition, many plastic piping manufacturers offer product catalogs and manuals that provide excellent information concerning the design and use of their materials.

The principal plastic piping material specifications are issued by the American Society for Testing and Materials (ASTM). Earlier ASTM standards classified plastic materials by type, grade, and class in accordance with three important properties. ASTM used a code that consisted of four digits and a product letter prefix indicating the resin. The four digits stood for:

1st digit	Type of resin
2nd digit	Grade of resin
3rd and 4th digits	Hydrostatic pressure divided by 100.

With the increase in the types and uses for plastic piping materials, the need arose to classify plastic piping materials by more than three properties. To meet this need, a number of ASTM materials standards have gone to a cell classification system. With this system, a property cell number according to the property value defines each of the primary properties. For the designer, this cell classification is a major improvement in specifying piping materials. It is not always sufficient, however, and the manufacturer is still a primary source for information when specifying plastic piping materials.

Thermoplastic piping materials, like many other materials, are affected by weathering, which is a general term used to cover the entire range of outdoor environmental conditions. Thermoplastic piping materials that include appropriate weathering protection have been used in various outdoor applications and have provided many years of service. Plastic piping systems that are intended for continuous outdoor use must have a material composition that provides weather resistance for the specific conditions involved. Most thermoplastic piping has additives, such as ultraviolet absorbers and antitoxins, that prevent the plastic pipe from degrading from weathering.

Available Products

Thermoplastics are the primary plastic piping material in use today. They account for the largest percentage of plastic pipe in use and have the widest range of applications. Polyvinyl chloride (PVC) makes up the majority of the thermoplastic piping market; polyethylene is the second most popular.

Thermoplastics differ significantly in their properties and their suitability for various uses. To properly use thermoplastic piping materials, the engineer and designer must have a good understanding of the different thermoplastic materials and their proper applications.

Thermoplastics are a popular piping material mainly because of their low cost, ease of fabrication (usually by extrusion), and long life. This popularity has in-

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creased laboratory and field experience and has helped develop a significant amount of knowledge and technical data. The increased knowledge has resulted in recommendations about the design, installation, use, limitations, and material properties of thermoplastic piping materials. Table 2.2 lists some of the important typical properties and applications of the most popular thermoplastic piping materials.

Polyvinyl Chloride (PVC). This plastic has the broadest range of applications in piping systems and its use has grown more rapidly than that of other plastics. PVC has good chemical resistance to a wide range of corrosive fluids.

The two principal types of PVC used in the manufacture of pipe and fittings are Type I and Type II (ASTM D 1784). Type I, also called unplasticized or rigid PVC, contains a minimum of processing aids and other additives and has maximum tensile and flexural strength, modulus of elasticity, and chemical resistance. It is more brittle, however, and has a maximum service temperature under stress of about 150°F, lower thermal expansion than Type II, and does not support combustion. Type II PVC, which is modified with rubber to render it less rigid and tougher, also is called high-impact, flexible, or non-rigid PVC. It has lower tensile and flexural strength, lower modulus of elasticity, lower heat stability, and less chemical resistance than Type I. With ultraviolet (UV) stabilization, PVC piping material provides

TABLE 2.2 Properties and Applications

Material	Properties	Temperature limit, °F	Joining methods	Application
PVC	Outstanding resistance to most corrosive fluids Offers more strength and rigidity than most other thermoplastic pipe	158	Cementing Threading Heat fusion	Drain, waste, and vent Sewage Potable water Well casings Chemical pro processing
CPVC	Has the same properties as PVC, but can be used at higher temperatures	212	Same as PVC.	Used mainly in high-temperature applications
PE	Offers a relatively low mechanical strength but has good chemical resistance and is flexible at low temperatures	140	Heat fusion Insert fitting	Potable water Irrigation and sprinkler Corrosive chemical transport Gas distribution Electrical conduit
ABS	This pipe is rigid and has high-impact resistance down to –40° F	158	Cementing Threading Mechanical seal devices	Drain, waste, and vent Potable water Sewer Treatment plants
PP	Good high-temperature properties and outstanding chemical resistance	194	Heat fusion Threading	Chemical waste Natural gas Oil field

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good long-term service in outdoors applications. The ability of the PVC material to withstand weathering depends on the type of UV stabilization and the amount of UV exposure.

The improvements made through research and the availability of product standards for special uses have increased PVC acceptance by designers, contractors, and building code officials. It is used in drain-waste-vent (DWV) applications, in storm, sanitary, water main, and natural gas distribution, and in industrial and process piping. The fastest growing application in North America is for municipal water and sewer systems. PVC pipe also is used as a conduit for wiring (both electrical and communications). The principle joining techniques for PVC piping is solvent cementing and elastomeric seals.

ASTM has developed a new version of ASTM D 1784 *Standard Specification for Rigid Polyvinyl Chloride and Chlorinated Polyvinyl Chloride Compounds*. This standard classifies PVC materials according to the nature of the polymer and five main properties instead of using the type and grade system. Cell-class limits that describe the polymer and four of the main properties are shown in Table 2.3. Chemical resistance, the fifth main property, is shown in Table 2.4.

Many piping standards still reference the older type and grade designation system. To assist in the conversion, new releases of ASTM D 1784 include a table (see Table 2.5) that cross-references the older with the new cell classifications.

ASTM D 4396 Standard Specification for Rigid Polyvinyl Chloride (PVC) and Related Plastic Compounds for Non-Pressure Piping Products is the PVC specification for non-pressure uses. Table 2.6 lists some physical properties of PVC pipe material.

Chlorinated PVC (CPVC). The basic resin in this plastic is made by post-chlorination of PVC. CPVC has essentially the same properties as Type I PVC material, but it has the added advantage of withstanding temperatures up to 212°F. Although it is suitable for the same piping applications as Type I PVC, the higher cost of CPVC restricts its use to that of conveying hot fluids. CPVC pipe can be used in water distribution lines at up to 100 psi working pressure at 180°F. As a result of the pressure and temperature ratings, CPVC pipe now replaces copper pipe in many areas of Europe and the United States.

Table 2.7 lists some physical properties of CPVC pipe material.

Polyethylene (PE). PE pipe materials are less strong and rigid than PVC materials at ambient temperatures. Because of its flexibility, ductility, and toughness, however, PE pipe materials are the second most widely used. Pipe made from PE has a relatively low mechanical strength but it exhibits good chemical resistance and flexibility and generally is satisfactory for use at temperature below 122°F. The temperature limitation, however, is offset by good flexibility retention down to −67°F. Polyethylene piping plastics are classified into three types based on density: low density (Type I), medium density (Type II) and high density (Type III). The most popular are Types II and III. The mechanical strength and chemical and temperature resistance

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TABLE 2.3 Cell Classification Limits for PVC Material ASTM D 1784

Designation order number	Property	Cell limits								
		0	1	2	3	4	5	6	7	8
1	Base resin	Unspecified	Polyvinyl Chloride	Chlorinated polyvinyl chloride	Vinyl copolymer					
2	Minimum Impact strength Ft-lb/in of notch	Unspecified	<0.65	<0.65	1.5	5.0	10.0	15.0		
3	Minimum Tensile strength Psi	Unspecified	<5000	<5000	6000	7000	8000			
4	Minimum Modulus of elasticity in tension Psi	Unspecified	<280,000	<280,000	320,000	360,000	400,000	440,000		
5	Minimum Deflection temperature under load 264 psi	Unspecified	<131	<131	140	158	176	194	212	230

Note: The minimum property value will determine the cell number.

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TABLE 2.4 Chemical Resistance ASTM D 1784

	Suffix			
	A	B	C	D
H_2SO_4 (93%), 14 days immersion at 55 +/−2°C				
Change in weight				
Increase, max %	1.0[1]	5.0[1]	25.0	NA
Decrease , max %	0.1[1]	0.1[1]	0.1[1]	NA
Change in flexural yield strength				
Increase, max %	5.0[1]	5.0[1]	5.0	NA
Decrease, max %	5.0[1]	25.0[1]	50.0	NA
H_2SO_4 (80%), 30 days immersion at 60 +/−2°C				
Change in weight				
Increase, max %	NA	NA	5.0	15.0
Decease , max %	NA	NA	5.0	0.1
Change in flexural yield strength				
Increase, max %	NA	NA	15.0	25.0
Decrease, max %	NA	NA	15.0	25.0
ASTM Oil Number 3, 30 days immersion at 23°C				
Change in weight				
Increase, max %	0.5	1.0	1.0	10.0
Decease , max %	0.5	1.0	1.0	0.1

[1] Specimens washed in running water and dried by an air blast or other mechanical means shall show no sweating within 2 hours after removal from the acid bath.

NA = not applicable

TABLE 2.5 Comparison of Older and Newer Designations

Type and grade classification from former specification D 1784-65T	Cell classification class from Tables 2.2 and 2.3
Rigid PVC materials	
Type I, Grade 1	12454-B
Type I, Grade 2	12454-C
Type I, Grade 3	11443-B
Type II, Grade 1	14333-D
Type III, Grade 1	13233
CPVC	
Type IV, Grade 1	23447-B

increases with density, whereas creep diminishes as the density increases. Most pressure PE pipe is made from Type II and Type III materials.

ASTM D 3350 is the primary specification for classifying PE pipe materials. This standard characterizes PE piping materials according to a cell classification system, which sequentially identifies seven physical properties by a matrix with the specified range of cell values for each of the properties. Table 2.8 shows the physical properties specified in ASTM D 3350 and the range for each property.

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TABLE 2.6 Physical Properties of PVC Material

ASTM test	Property	Rigid	Flexible
	Physical		
D792	Specific gravity	1.30–1.58	1.20–1.70
D792	Specific volume (in^3/lb)	20.5–19.1	—
D570	Water absorption, 24 hours, ⅛ in. thick (%)	0.04–0.4	0.15–0.75
	Mechanical		
D638	Tensile strength (psi)	6000–8000	1500–3500
D638	Elongation (%)	50–150	200–450
D638	Tensile modulus (10–5 psi)	3.5–10	—
D790	Flexural modulus (10–5 psi)	3–8	—
D256	Impact strength, izod (ft-lb/in. of notch)	0.4–20.0	—
D785	Hardness, Shore	65–85D	50–100A
	Thermal		
C177	Thermal conductivity (10–4 cal-cm/sec-cm–2-ºC)	3.5–5.0	3.0–4.0
D696	Coefficient of thermal expansion (10–5in./in.-ºF)	1.2–5.6	3.9–13.9
D648	Deflection temperature (ºF)		
	At 264 psi	140–170	—
	At 66 psi	135–180	
	Electrical		
D149	Dielectric strength (V/mil) short time, ⅛ in. thick	350–500	300–400
D150	Dielectric constant at 1 kHz	3.0–3.8	4.0–8.0
D150	Dissipation factor at 1 kHz	0.009–0.017	0.07–0.16
D257	Volume resistivity (ohm-cm) at 73ºF, 50% RH	>10–16	10–11 to 10–15
D495	Arc resistance(s)	60–80	—

TABLE 2.7 Physical Properties of CPVC Material

Physical Property	ASTM Test Method	
Specific gravity	D 792	1.55
Modulus of elasticity in tension (psi at 73°F)	D 638/D 2105	420,000
Tensile (psi at 73°F)	D 638/D 2105	8400
Flexural Strength (psi)	D 790	15,350
Coefficient of thermal expansion (inch per inch per degree F)	D 696	3.8

An ASTM Material Designation Code, PE 2406 or PE 3408, also identifies thermoplastic PE materials for pressure piping systems. The first two numbers identify ASTM D 3350 cell values for density and slow crack growth resistance. The

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TABLE 2.8 Cell Classification Limits for PE Material ASTM D 3350

Property	Test method	0	1	2	3	4	5	6	7
Density, gm/cm3	D 1505	Unspecified	0.910-0.925	0.926–0.940	0.941–0.955	>0.955	—	-	Specify value
Melt index, gm/10 min.	D 1238	Unspecified	>1.0	1.0–0.4	<0.4-0.15	<0.15	†	‡	Specify value
Flexural modulus, 1000 psi	D 790	Unspecified	<20,000	20,000 –<40,000	40,000 –<80,000	80,000 –<110,000	110,000 –<160,000	>160,000	Specify value
Tensile strength, 1000 psi	D 638	Unspecified	<2200	2200–<2600	2600–<3000	3000–<3500	3500–<4000	>4000	Specify value
Slow crack Growth resistance 1. ESCR									
Test condition	D 1693	Unspecified	A	B	C	C			
Test duration			48	24	192	600	—	—	Specify value
Failure, max %			50	50	20	20			
2. PENT (hours)									
Molded plaque, 80°C., 2.4 MPa, Notch depth	F 1473	Unspecified	0.1	1	3	10	30	100	Specify value
Hydrostatic design basis, (psi)	D 2837	NPR *	800	1000	1250	1600			
		A	B	C	D	E			
Color and UV stabilizer	D 3350	Natural	Color	Black with min. 2% carbon black	Natural with UV stabilizer	Color with UV stabilizer			

*NPR = Not Pressure Rated

†Materials with melt index less than cell 4 but which have flow rate <4.0g/10 min when tested according to D 1238, Condition 190/21.6.

‡Material with melt index less than cell 4 but which have flow rate <0.30g/10 min when tested according to D 1238, Condition 310/21.5.

PLASTIC PIPING CHARACTERISTICS

last two numbers identify the materials hydrostatic design stress in psi divided by 100 with tens and units dropped.

Like PVC, PE piping material with ultraviolet (UV) stabilization provides good long-term service in outdoors applications. The ability of the PE material to withstand weathering depends on the type of UV stabilization and the amount of UV exposure.

PE pipe is available in both schedule number and standard dimension (SDR) sizes. Its principal applications are irrigation and sprinkler systems, drainage, chemical transport, gas distribution pipe, and electrical conduit systems. The typical physical properties for PE material are listed in Table 2.9.

Specialty PE Pipes. A relatively new development in PE piping is the introduction of ultrahigh molecular weight (UHMW) PE and cross-linked PE plastic piping materials. The UHMW PE has considerably higher resistance to stress cracking but is more costly than conventional PE piping material. It offers an extra margin of safety when used in sustained pressure conditions in comparison with pipe made from lower molecular weight resin. It is suitable for certain applications in the chemical industry where stress-cracking resistance has been a limiting factor for the conventional PE pipe.

Cross-linked PE piping material, when compared to ordinary PE pipe, displays greater strength, higher stiffness, and improved resistance to abrasion and to most chemicals and solvents at elevated temperatures up to 203°F. Pipe made from cross-linked PE also has high-impact resistance even at sub-zero temperatures. It is used in applications too severe for ordinary PE pipe. The joining technique used is threading.

Acrylonitrile-butadiene-styrene (ABS). ABS plastic is a copolymer made from the three monomers-acrylonitrile (at least 15 percent), butadiene, and styrene. It is a rigid plastic with good impact resistance at temperatures down to -40°F and up to 176°F. ABS is used mainly for drain-waste-ventilation (DWV) pipe and fittings, but it also is used in solvent cement for installing pipe in various applications. The most common applications for ABS pipe material are:

- Slurry lines
- Dewatering lines
- Water lines
- Pump lines.

Like other plastic piping materials, ABS is 70 percent to 90 percent lighter than steel and can be installed without heavy equipment. It offers excellent resistance to most chemicals and has a smooth interior surface that prevents mineral buildup and scaling. Solvent welding or threading can be used to join ADS pipe efficiently. ABS piping material also can be connected to other piping materials with Victaulic couplings or flanges. ABS piping material usually contains carbon

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TABLE 2.9 Typical Physical Properties of PE Material

ASTM test	Property	Low density	Medium density	High density	Ultrahigh molecular weight
	Physical				
D792	Specific gravity	0.910–0.925	0.926–0.940	0.941–0.965	0.9258–0.941
D792	Specific volume (in^3/lb)	30.4–29.9	29.9–29.4	29.4–28.7	29.4
D570	Water absorption, 24 hours, ⅛ in. thick (%)	<0.1	<0.1	<0.1	<0.1
	Mechanical				
D638	Tensile strength (psi)	600–2300	1200–3500	3100–5500	4000–6000
D638	Elongation (%)	90–800	50–600	20–1000	200–500
D638	Tensile modulus (10–5 psi)	0.14–0.38	0.25–0.55	0.6–1.8	0.20–1.10
D790	Flexural modulus (10–5 psi)	0.08–0.60	0.60–1.15	1.0–2.0	1.0–1.7
D256	Impact strength, izod (ft-lb/in. of notch)	No break	0.5–16	0.5–20	No break
D785	Hardness, Rockwell R	10	15	65	67
	Thermal				
C177	Thermal conductivity (10–4 cal-cm/sec-cm–2-°C)	8.0	8.0–10.0	11.0–12.4	11.0
D696	Coefficient of thermal expansion (10–5in./in.-°F)	5.6–12.2	7.8–8.9	6.1–7.2	7.8
D648	Deflection temperature (°F)				
	At 264 psi	90–105	105–120	110–130	118
	At 66 psi	100–121	120–165	140–190	170

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TABLE 2.9 *(continued)* Typical Physical Properties of PE Material

ASTM test	Property	Low density	Medium density	High density	Ultrahigh molecular weight
		Electrical			
D149	Dielectric strength (V/mil) short time, ⅛ in. thick	460–700	460–500	900 k V/cm	
D150	Dielectric constant at 1 kHz	2.25–2.35	2.25–2.35	2.30–2.35	2.30–2.35
D150	Dissipation factor at 1 kHz	0.0002	0.0002	0.0003	0.0002
D257	Volume resistivity (ohm-cm) at 73°F, 50% RH	10–15	10–15	10–15	10–18
D495	Arc resistance(s)	135–160	200–235	—	—
		Optical			
D542	Refractive index	1.51	1.52	1.54	—
D1003	Transmittance (%)	4–50	4–50	10–50	—

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black to provide protection from sunlight. Non-black ABS pipe is not recommended for outdoor use.

Tables 2.10 and 2.11 list some of the properties of ABS piping material.

Polybutylene (PB). Polybutylene piping has practically no creep and has excellent resistance to stress cracking. It is flexible, and in many respects similar to Type III polyethylene, but is stronger. Polybutylene plastic piping is relatively new, and thus far its use has been limited to the conveyance of natural gas and to water distribution systems. Its high temperature grade can resist temperatures of 221-230°F. Table 2.12 lists some important physical properties of PB pipe material.

Polypropylene (PP). Polypropylene (PP) is an economical material that offers a combination of outstanding physical, chemical, mechanical, thermal, and electrical properties not found in other thermoplastics. Compared to low- or high-density PE, PP has a lower impact strength, but superior working temperature and tensile

TABLE 2.10 ABS Physical Properties

Mechanical			
ASTM test	Property		
D638	Tensile strength at yield	4500 psi	31.0 MPa
D638	Elongation at yield	3.0%	3.0%
D638	Elongation at fail	30%	30%
D838	Modulus of elasticity (in tension)	220,000 psi	1517MPa
D256	Izod impact, notches ½ in. × ½ in. bar, .010 in. notch	7.0 ft/lbs. per inch of notch	0.37J/mn of notch
D690	Thermal expansion (linear)	5.2 × 10.5 in./in./ºF	9.4 × 10.5 mm/mm/ºC
D792	Specific gravity	1.04	1.04
Thermal			
D648	Deflection temperature under load ½in. × ½in. bar, injection model	185ºF @ 264 psi fiber stress	55ºC @ 1.82 MPa fiber stress

TABLE 2.11 Recommended Design Pressures at Elevated Temperatures

Temperature		Percent of rated pressures
ºF	ºC	
73.4	23	100%
90	32	86%
100	38	81%
140	60	60%

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TABLE 2.12 Physical Properties of Polybutylene (PB) Material

Physical property	ASTM test method	
Specific gravity	D 792	0.92
Modulus of elasticity in tension (psi at 73°F)	D 638/D 2105	350,000
Tensile (psi at 73°F)	D 638/D 2105	3800
Flexural strength (psi)	D 790	3000+
Coefficient of thermal expansion (inch per inch per degree F)	D 696	7.2

strength. PP is a tough, heat-resistant, semi-rigid material that is ideal for the transfer of hot liquids or gases. Polypropylene-based piping is also the lightest-weight plastic material and generally has better chemical resistance than other plastics. PP is used in some pressure piping applications, but its primary use is in low-pressure lines. Polypropylene plastic pipe is used for chemical (usually acid) waste drainage systems, natural gas and oil-field systems, and water lines. The maximum temperature for non-pressure piping is 194°F. Pipe lengths are joined by heat fusion, threading (i.e., with heavy pipe) and mechanical seal devices. With ultraviolet (UV) stabilization, PP piping material provides good long-term service in outdoors applications. The ability of the PP material to withstand weathering depends on the type of UV stabilization and the amount of UV exposure. See Table 2.13 for properties of PP piping material.

PLASTIC PIPING COMPONENTS

Many plastic piping components are available commercially and the list continues to grow. When considering a plastic piping fitting or valve, manufacturers' catalogs are a valuable source of what is available. Many of the manufactures have Web sites and online catalogs of their equipment. The Plastic Pipe Institute is an excellent source for links to plastic pipe manufacturers and suppliers on the Web and can be found at www.plasticpipe.org.

Thermoplastic fittings usually are injection molded. Molded fittings usually cost less and have higher pressure ratings than fabricated fittings. Most plastic fittings are molded in sizes up to eight inches; most 10 inches and above are fabricated.

Plastic valves fall into the same general categories as metal valves and have the same basic parts, such as stems or shafts, seats, seals, bonnets, hand wheels, and levers. Plastic valves are lighter, usually have better chemical resistance, and have less friction loss through the valve. Plastic valves can be specified to meet the pressure rating of the plastic pipe being used. Valve ends for joining to the pipe are available for socket fusion, threaded, flanged, and spigot ends. Plastic valves also have different types of material for the seats and seals to support the different products being handled by plastic piping systems.

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TABLE 2.13 Typical Properties of Polypropylene (PP) Pipe Material

ASTM or UL test	Property	Unmodified resin	Glass reinforced	Impact grade
	Physical			
D792	Specific gravity	0.905	1.05–1.24	0.89–0.91
D792	Specific volume (in^3/lb)	30.8–30.4	24.5	30.8–30.5
D570	Water absorption, 24 hours, ⅛ in. thick (%)	0.01–0.03	0.01–0.05	0.01–0.03
	Mechanical			
D638	Tensile strength (psi)	5000	6000–14,500	2800–4400
D638	Elongation (%)	10–20	2.0–3.6	350–500
D638	Tensile modulus (10–5 psi)	1.6	4.5–9.0	1.0–1.7
D790	Flexural modulus (10–5 psi)	1.7–2.5	3.8–8.5	1.2–1.8
D256	Impact strength, izod (ft-lb./in. of notch)	0.5–2.2	1.0–5.0	1.0–15
D785	Hardness, Rockwell R	80–110	110	50-85
	Thermal			
C177	Thermal conductivity (10–4 cal-cm/sec-cm–2-ºC)	2.8	—	3.0–4.0
D696	Coefficient of thermal expansion (10–5in./in.-ºF)	3.2–5.7	1.6–2.9	3.3–4.7
D648	Deflection temperature (ºF)			
	At 264 psi	125–140	230–300	120–135
	At 66 psi	200–250	310	160–210
UL94	Flammability rating	HB	HB	HB
	Electrical			
D149	Dielectric strength (V/mil) short time, ⅛ in. thick	500–660	475	500–650
D150	Dielectric constant at 1 kHz	2.2–2.6	2.36	2.3
D150	Dissipation factor at 1kHz	0.0005–0.0018	0.0017	0.0003
D257	Volume resistivity (ohm-cm) at 73ºF, 50%RH	10–17	2 × 10–16	10–15
D495	Arc resistance(s)	160	100	—

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CHAPTER 3
FLUID FLOW

GENERAL

The main purpose of piping systems is to transport fluids from one location to another. Numerous standard fluid flow equations are used to calculate the flow and pressure drop of pipe and fittings. Each equation is unique and might have limitations associated with its use. This chapter will describe many of the various equations used for fluid flow calculations, with a focus on plastic piping systems. It is important that the engineer uses an equation that is appropriate for the flow condition being analyzed.

A fluid is any liquid or gas that cannot sustain its shape when subjected to a tangential or shearing force when at rest. This continuous and irrecoverable change of position of one part of the material relative to another part when under shear stress constitutes flow, a characteristic property of fluids. Liquids and gases are classified together as fluids because, over a wide range of situations, they have identical equations of motion and exhibit the same flow phenomena. Liquids change their volume slightly with significant variations in pressure, while gases tend to expand and completely fill any container. With gases, a change in pressure is accompanied by a change in volume.

LIQUID FLOW

The following variables and nomenclature are used throughout the liquid flow section:

C_w = Hazen-Williams Coefficient
D = Inside pipe diameter, ft

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d = Inside pipe diameter, in.
f = Friction factor, dimensionless
g = Gravitational acceleration, ft/sec^2
g_c = Gravitational constant, 32.174 ft/sec^2
h_p = Head gain, ft
h_L = Head loss, ft
h_f = Friction head loss, ft
h_m = Head loss due to minor loss valve or fitting, ft
h_w = H_2O pressure, in.
K = Resistance coefficient for valve or fitting
k = Internal pipe wall roughness, ft
L_f = Pipe length, ft
P = Pressure, lb/in^2 (psia)
p = Pressure, lb/ft^2, psf
ΔP = Change in pressure, psia
P_1 = Inlet or upstream pressure, psia
P_2 = Outlet or downstream pressure, psia
Q = Flow rate, gallons/min
Q_h = Volumetric flow rate, ft3/hr (cfh)
Re = Reynolds number, dimensionless
Sg = Specific gravity, dimensionless
v = Velocity, ft/sec
W = Weight, lb
z = Elevation, ft
Δz = Change in elevation
ν = Kinematic viscosity, ft^2/sec
μ = Absolute (dynamic) viscosity, lbm/ft-sec
ρ = Density of fluid, lb/ft^3
γ = Specific weight, lb/ft^3

Table 3.1 lists some general formulas used for liquid hydraulics.
Table 3.2 lists some conversion factors used in liquid hydraulics.

The Energy Principle

Although there is no such thing as a truly incompressible fluid, this term is used for liquids. The first law of thermodynamics states that for any given system, the change in energy is equal to the difference between the heat transferred to the sys-

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TABLE 3.1 General Formulas Used for Liquid Hydraulics

Formulas	Symbols
$A = \frac{\pi D^2}{4}$	A = Cross-sectional area of pipe, ft^2
$H = \frac{2.31P}{Sg}$	D = Inside diameter of pipe, ft
$H = \frac{P}{0.433Sg}$	H = Pressure measured in ft of head
$P = \frac{HSg}{2.31}$	P = Pressure measured in lb/in^2
$Sg = \frac{W\text{ (liquid)}}{W\text{ (water)}}$	Q = Flow rate in ft^3/sec
$V = \frac{Q}{A}$	Sg = Specific gravity
	V = Velocity in ft/sec
	W = Specific weight
Volume of Pipeline Fill	
$r = \frac{ID}{2}$	r = Pipe radius
$G = \pi r^2(L \times 12)0.004329$	ID = Inside pipe diameter
$V = \frac{G}{L}$ or $V = \frac{B}{L}$	L = Length in ft
$B = \frac{ID^2 5.13L}{5280}$	V = Pipeline fill per ft
	G = Pipeline fill per length in gal
	B = Pipeline fill per length in barrels

TABLE 3.2 Conversion Factors

1 ft^3 = 7.48 gallons	ft^3/sec = 642 BPH
1 barrel = 42 gallons	ft^3/sec = 449 GPM
1 gallon = 231 in^3	1 GPM = 1.43 BPH
1 ft^3 = 1728 in^3	

tem and the work done by the system on its surroundings during a given time interval. This energy represents the total energy of the system. In piping applications, energy often is converted into units of energy per unit weight resulting in units of length. Engineers use these length equivalents to get a better feel for the resulting behavior of the system. In pipeline hydraulics, we express the state of the system in terms of "head" or feet of head. The energy at any point in a piping system often is identified as:

$$\text{Pressure head} = p/\gamma$$
$$\text{Elevation head} = z$$
$$\text{Velocity head} = v^2/2g$$

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These quantities can be used to express the head loss or head gain between two locations using the energy equation.

The Energy Equation

In addition to pressure head, elevation head, and velocity head, head also can be added to the system (usually by a pump) and head can be removed from the system due to friction or other disturbances within the system. These changes in head are referred to as head gains and head losses. By balancing the energy between two points in the system, we can obtain the energy equation (Bernoulli's Equation):

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_p = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} + h_L \tag{3.1}$$

The basic approach to all piping systems is to write the Bernoulli Equation between two points, connected by a streamline, where the conditions are known. The total head at point 1 must match with the total head at point 2, adjusted for any increases in head because of pumps, losses because of pipe friction, and so-called "minor losses" because of entries, exits, fittings, etc. The parts of the energy equation can be combined to express two useful quantities, the hydraulic grade and the energy grade.

Hydraulic and Energy Grades

The hydraulic grade line (HGL) and the energy grade line (EGL) are two useful engineering tools in the hydraulic design of a system that is in a dynamic state. The hydraulic grade is the sum of the pressure head and the elevation head. This represents the height that a water column would raise in a piezometer. When plotted in a profile, this is referred to as the hydraulic grade line or HGL (see Figure 3.1).

The energy grade is the sum of the hydraulic grade and the velocity head and represents the height that a column of water would raise in a pitot tube. When plotted in a profile, this is referred to as the energy grade line, or EGL (see Figure 3.1).

Pipe Sizing

Fluid flow is a basic component of sizing a piping system. The fluid flow design determines the minimum acceptable pipe diameter required for transferring the fluid efficiently. The main factors in determining the minimum acceptable pipe diameter are the design flow rates and pressures losses. The design flow rates are based on system demands that usually are established in the design phase of a project. Before the determination of the minimum inside diameter can be made, service conditions must be reviewed to determine operational requirements, such as the recommended fluid velocity, and liquid characteristics, such as viscosity, temperature, and solids density.

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FLUID FLOW

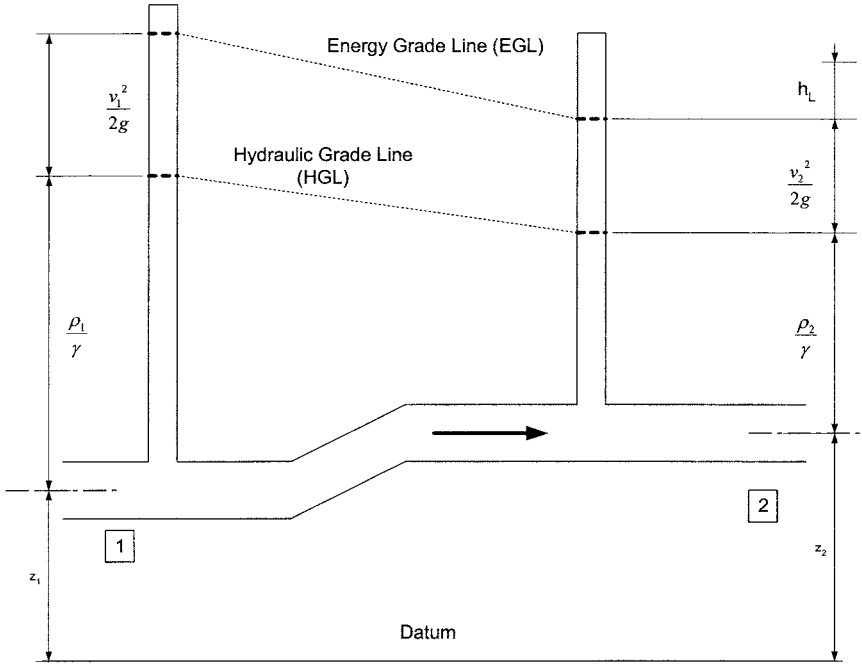

FIGURE 3.1 Energy grade line.

For normal liquid service applications, the acceptable fluid velocity in pipes is around 7 ft/sec ± 3 ft/sec. The maximum velocity at piping discharge points usually is limited to 7 ft/sec. These velocity ranges are considered reasonable design targets for normal applications. Other limiting factors, such as pressure transient conditions, however, can overrule. In addition, some applications can allow greater velocities based on general industry practices, such as boiler feed water and petroleum liquids.

Pressure losses throughout a piping system should be designed to provide an optimum balance between the installed cost of a piping system and operating cost of the system. The primary factors that will affect the cost and system operating performances are the inside pipe diameter (and the resulting fluid velocity), materials of construction, and pipe routing.

Energy Losses in Pipes

When a fluid is transported inside a pipe, the pipe's inside diameter determines the allowable flow rate. Several factors might cause the energy loss (hL) in a piping system, with the main cause friction between the fluid and the pipe wall. Liquids in the pipe resist flowing because of viscous shear stresses within the fluid and friction along the pipe walls. This friction is present throughout the length of

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the pipe. As a result, the energy grade line (EGL) and the hydraulic grade line (HGL) drop linearly in the direction of flow. Flow resistance in pipe results in a pressure drop, or loss of head, in the piping system.

Localized areas of increased turbulence and disruption of the streamlines are secondary causes of energy loss. These disruptions usually are caused by valves, meters, or fittings and are referred to as minor losses. When considered against the friction losses within a piping system, the minor losses often are considered negligible and sometimes are not considered in an analysis. While the term minor loss often is applicable for large piping systems, it might not always be the case. In piping systems that have numerous valves and fittings relative to the total length of pipe, the minor losses can have a significant impact on the energy or head losses.

Pressure Flow of Liquids

Many equations approximate the friction losses that can be expected with the flow of liquid through a pressure pipe. The two most frequently used equations in plastic piping systems are:

Darcy-Weisbach Equation

Hazen-Williams Equation

The Darcy-Weisbach Equation applies to a wide range of fluids, while the Hazen-Williams Equation is based on empirical data and is used primarily in water modeling applications. Each of these methods calculates friction losses as a function of the velocity of the fluid and some measure of the pipe's resistance to flow (pipe wall roughness). Typical pipe roughness values for these methods are shown in Table 3.3. These values can vary depending on the product manufacturer, workmanship, age, and many other factors.

Darcy-Weisbach Equation. Friction losses in a piping system are a complex function of the system geometry, the fluid properties, and the flow rate in the system. By observation, the head loss is roughly proportional to the square of the flow rate in most engineering flows (fully developed, turbulent pipe flow). This observation leads us to the Darcy-Weisbach Equation for head loss from friction:

$$h_f = f \frac{L_f}{D} \frac{v^2}{2g_c} \tag{3.2}$$

The Darcy-Weisbach Equation is a generally accepted method for calculating friction losses from liquids flowing in full pipes. It recognizes the dependence on pipe diameter, pipe wall roughness, liquid viscosity, and flow velocity. Darcy-Weisbach is a general equation that applies equally well at any flow rate and any incompressible fluid.

Depending upon the Reynolds number, the friction factor is a function of the relative wall roughness of the pipe, the velocity of the fluid, and the kinematic

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TABLE 3.3 Pipe Roughness Values

Material	Hazen-Williams *Cw*	Darcy-Weisbach roughness height k (feet)
Asbestos cement	140	0.000005
Brass	135	0.000005
Brick	100	0.002
Cast iron; new	130	0.00085
Concrete		
Steel forms	140	0.006
Wooden forms	120	0.002
Copper	135	0.000005
Corrugated metal	—	0.15
Galvanized iron	120	0.0005
Glass	140	0.000005
Plastic	150	0.000005
Steel; new unlined	145	0.00015
Wood stave	120	0.0006

viscosity of the fluid. Liquid flow in pipes can be laminar or turbulent, or it can be in a transition between the two. For laminar flow (Reynolds number below 2000), the head loss is proportional to the velocity rather than the velocity squared and the pipe wall roughness has no effect. The friction factor calculation is:

$$f = \frac{64}{R_E} \tag{3.3}$$

Laminar flow can be characterized as consisting of a series of thin shells that are sliding over one another. The velocity of the fluid is the greatest at the center and the velocity at the pipe wall is zero.

In the turbulent flow region, it is not possible to obtain an analytical solution for the friction factor as we do for laminar flow. Most of the data available for evaluating the friction factor in turbulent flow have been derived from experiments. For turbulent flow (Reynolds number above 4000), the friction factor is dependent upon the pipe wall roughness as well as the Reynolds number. For turbulent flow, Colebrook (1939) found an implicit correlation for the friction factor in round pipes. This correlation converges well in a few iterations.

$$\frac{1}{\sqrt{f}} = -2 \log\left[\frac{k}{3.7d} + \frac{2.51}{R_E\sqrt{f}}\right] \tag{3.4}$$

$$R_E = \frac{vD}{vy} \tag{3.5}$$

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or

$$R_E = \frac{3162Q}{dk} \tag{3.6}$$

The familiar Moody Diagram is a log-log plot of the Colebrook correlation on an axis of the friction factor and the Reynolds number, combined with the $f = 64/\mathrm{Re}$ result for laminar flow.

For turbulent flow, appropriate values for the friction factor can be determined using the Swamme and Jain Equation, which provides values within 1 percent of the Colebrook Equation over most of the useful ranges:

$$f = \frac{1.325}{\left[In\left(\frac{k}{3.7d} + \frac{5.74}{R_E^{0.9}}\right)\right]^2} \tag{3.7}$$

Hazen-Williams Equation The Hazen-Williams Equation is used primarily in the design and analysis of pressure pipe for water distribution systems. This equation was developed experimentally with water and, under most conditions, should not be used for other fluids. The Hazen-Williams formula for water at 60°F, however, can be applied to liquids that have the same kinematic viscosity as water. This

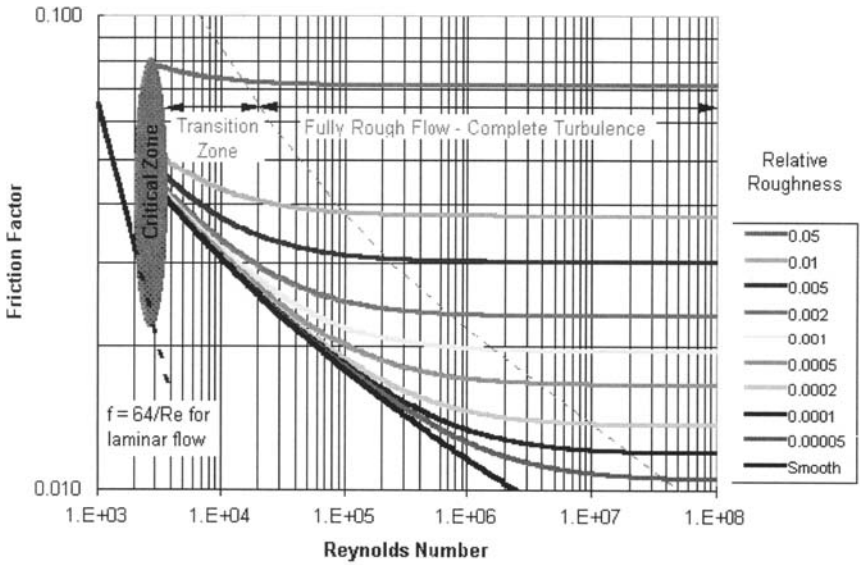

FIGURE 3.2 Reynolds number.

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equation includes a roughness factor *Cw*, which is constant over a wide range of turbulent flows and an empirical constant.

$$h_f = \frac{3.02L_f}{D^{1.16}}\left(\frac{v}{Cw}\right)^{1.85} \tag{3.8}$$

For a simpler solution to fluid flow in plastic pipe, consider this version of the Hazen-Williams formula:

$$\Delta P_{100} = \frac{452Q^{1.85}}{Cw^{1.85}d^{4.86}} \tag{3.8}$$

where ΔP = Friction pressure loss, psi, per 100 feet of pipe.

The coefficient *Cw* is essentially a friction factor. Table 3.1 lists *Cw* values for various types of pipe.

The designer must use proper judgment to select pipe sizes that best meet the project conditions. The following considerations may be helpful:

- At a given flow rate, a larger diameter pipe will have a lower velocity and less pressure drop.
- At a given flow rate, a smaller diameter pipe will have higher velocity and increased pressure drop.
- The frictional head loss is less in larger diameter pipes than smaller pipe flowing at same velocity.

Minor Losses. Fluids flowing through a valve or fitting will have a friction head loss. Minor losses in pipes at these areas are caused by increased turbulence, which causes a drop in the energy and hydraulic grades at that point in the pipe system. The magnitude of the energy losses primarily depends on the shape of the fitting. The head or energy loss can be expressed by using the applicable resistance coefficient for the valve or fitting. The Darcy-Weisbach Equation then becomes:

$$h_m = K\frac{v^2}{2g_c} \tag{3.10}$$

$$K = f\frac{L_f}{D} \tag{3.11}$$

Equation 3.10 can be rearranged to express the fitting head loss as feet of straight pipe having the same head loss as the fitting.

$$L_f = \frac{KD}{f} \tag{3.12}$$

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To calculate head losses in piping systems with both pipe friction and minor losses use:

$$h_f = \left(f \frac{L_f}{D} + \sum K \right) \frac{v^2}{2g_c} \tag{3.13}$$

Typical K values for the fitting loss coefficients are in Table 3.4.

Table 3.5 lists the estimated pressure drop for thermoplastic lined fittings and valves.

Water Hammer/Pressure Surge

Flowing liquid has momentum and inertia. When flow is stopped suddenly, the mass inertia of the flowing stream is converted into a shock wave. Consequently, a high static head exists on the pressure side of the pipeline. Quick surge pressures are shock waves known as water hammer. Water hammer, or hydraulic transients, is caused by opening and closing (full or partial) valves, starting and stopping pumps, changing pump or turbine speed, reservoir wave action, and entrapped air. The pressure wave from water hammer races back and forth in the pipe, getting progressively weaker with each "hammer." Maximum surge pressure results when the time required to change a flow velocity a given amount is equal to or less than:

$$t \leq \frac{2L_f}{S} \tag{3.13}$$

TABLE 3.4 Fitting Loss Coefficients

Fitting	Description	K Value
Pipe entrance	Sharp edged	0.5
	Inward projected pipe	1.0
	Rounded	0.05
Pipe exit	All	1.0
Bends	90° standard elbow	0.9
	45° standard elbow	0.5
Tee	Standard, flow through run	0.6
	Standard, flow through branch	1.8
Valves	Globe, fully open	10
	Angle, fully open	4.4
	Gate, fully open	0.2
	Gate, ½ open	5.6
	Ball, fully open	4.5
	Butterfly, fully open	0.6
	Swing check, fully open	2.5

Notes: Hydraulic Institute, Pipe Friction Manual, 3rd Ed., Crane Company, Technical Paper 410.

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TABLE 3.5 Estimated Pressure Loss for Thermoplastic Lined Fittings and Valves

Size Inch	Standard 90° elbow	Tee through run	Tee through branch	Plug valve	Diaphragm valve	Vertical check valve	Horizontal check valve
1	1.8	1.2	4.5	2.0	7.0	6.0	16
1½	3.5	2.3	7.5	4.2	10	6.0	23
2	4.5	3.0	10	5.5	16	10	45
2½	5.5	4.0	12	NA	22	11	50
3	7.0	4.1	15	NA	33	12	58
4	10	6.0	20	NA	68	20	65
6	15	10	32	NA	85	31	150
8	19	14	42	NA	150	77	200
10	25	19	53	NA	NA	NA	NA

Notes: Data is for water expressed as equal length of straight pipe in feet.
NA = Part is not available from source.

Source: "Plastic Lined Piping Products Engineering Manual," page 48.

where L_f = is the length of the pipeline, feet
S = is the speed of the pressure wave, feet per seconds
t = is the time, seconds.

S is determined by the following:

$$S = \sqrt{\frac{(144E)K}{\left(\frac{w}{g}\right)\left(144E + \frac{KD}{t}\right)}} \tag{3.14}$$

where K = Bulk modulus of the liquid, psi (300,000 psi for water)
E = Modulus of elasticity of the pipe material, psi
w = Unit weight of fluid, lb/ft^3.

The excess pressure caused by the water hammer can be calculated by:

$$P_s = \frac{wSv_c}{144g} \tag{3.15}$$

where P_s = Change in pressure, psi
vc = Change in velocity, ft/sec, occurring within critical time.

Performing a water hammer analysis of a piping system is a complex task. Factors to be considered include pumping characteristics, fluid velocity, elevation changes, valve closing times, and piping geometry. Equation 3.15 calculates the maximum surge pressure for the given velocity change. Keeping the time to stop the flow at more than t (Equation 3.13) can minimize pressure changes. The

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greatest effects on the velocity of the liquid occur during the final stage of valve closure. A general guideline for gate valves with linear closure characteristics is to maintain a valve closure time of 10 times t. This should keep the pressure surge at about 10 percent to 20 percent of the surge developed by the t closure time.

Plastic piping materials have different characteristics and handle the effects of pressure surges differently. The designer should consult with the plastic pipe manufacturer concerning their products ability to handle pressure surges. For example, polyethylene (PE) pipe can handle short-term pressure surges above the design pressure rating of the pipe because of its short-term strength and flexibility. When under similar conditions, surge pressures in PE pipe are significantly less than surges seen in rigid pipe. For the same liquid and velocity change, surge pressures in PE pipe are about 50 percent less than PVC pipe. The fatigue endurance of the plastic piping material must be taken into account if the piping system has frequent or continuous pressure surges. A piping system encountering repeated stress could have a long-term strength loss. If the piping system will see frequent cyclical surge pressure, the total system pressure (including surge pressure) should not exceed the design pressure rating of the material.

COMPRESSIBLE GAS FLOW

Compressible flow implies that variations exist in the density of a fluid. The variations are caused by pressure and temperature changes from one point to another. The rate of change is important in the analysis of compressible flow and is connected closely with the velocity of sound. When dealing with compressible fluids, when the density change is gradual and not more than a few percent, the flow can be treated as incompressible by using an average density. If the change in pressure divided by the initial pressure is greater than 0.05, however, the effects of compressibility must be considered. In plastic piping systems, compressible flow is encountered most often in gases, such as natural gas. The following section provides many of the frequently used formulas in the design of plastic piping for natural gas applications. The following variables will apply to each equation described in the following pages:

Cw = Hazen-Williams Coefficient
d = Inside pipe diameter, inches
E = Pipeline efficiency factor
e = 2.71828, natural logarithm base
F = Transmission factor, dimensionless
f = Friction factor, dimensionless
G = Specific gravity of gas, dimensionless
H = Elevation, ft
ΔH = Change in elevation

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h = H_2O pressure, in.
k = Internal pipe wall roughness, in.
L_f = Pipe length, ft
L_m = Pipe length, miles
P = Pressure, lb/in^2 (psia)
ΔP = Change in pressure, psia
P_1 = Inlet or upstream pressure, psia
P_2 = Outlet or downstream pressure, psia
P_{atm} = Average atmospheric pressure, psia
P_{avg} = Average pressure along the pipeline segment, psia
P_b = Base pressure, psia
Q_h = Volumetric flow rate, ft^3/hr (cfh)
Q_d = Volumetric flow rate, ft^3/day (cfd)
Re = Reynolds Number, dimensionless
ΔT = Change in temperature
T_{avg} = Average gas flowing temperature, Rankine
T_b = Base temperature, Rankine
T_1 = Initial temperature of the gas, Rankine
T_2 = Temperature of the gas under the second conditions, Rankine
V_1 = Volume of the gas in original condition, ft^3
V_2 = Volume of the gas in second set of conditions, ft^3
v = Gas velocity, ft/sec
W = Weight of the gas, lb
Z = Gas compressibility factor, dimensionless
ν = Kinematic viscosity, ft^3/sec
μ = Absolute (dynamic) viscosity, lbm/foot-second
ρ = Density of fluid, lb/ft^3

Table 3.6 lists some general formulas used for gas hydraulics:

Gas Laws

Boyle's Law. If the temperature of the gas remains constant, the volume of a quantity of gas will vary inversely as the absolute pressure. This is expressed mathematically by Boyle's Law as:

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

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When using Boyle's Law, we are usually interested in the volume at the second set of conditions. For this purpose, the equation often is rewritten as:

$$V_2 = V_1 \frac{P_1}{P_2}$$

EXAMPLE 1

A quantity of gas at 70 psia has a volume of 1000 cubic feet. If the gas is compressed to 150 psia, what volume would it occupy? The barometric pressure is 14.7 psia and the temperature remains constant.

$$V_2 = 1000 \frac{70 + 14.7}{150 + 14.7} = 514.3 \text{ ft}^3$$

Charles' Law. Charles' Law states that the volume occupied by a fixed amount of gas is directly proportional to its absolute temperature, if the pressure remains constant. This empirical relation was formulated by the French physicist J.A. Charles about 1787 and reaffirmed later by Joseph Gay-Lussac. Charles' Law is expressed as:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

Like the example above, we usually are interested in the volume at a second set of temperature conditions, so this equation often is rewritten as:

$$V_2 = V_1 \frac{T_1}{T_2}$$

Charles' Law also states that if the volume of a quantity of gas does not change, the absolute pressure will vary directly as the absolute temperature. This is expressed as:

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

If we are interested in the pressure at a second temperature condition, the equation can be expressed as:

$$P_2 = P_1 \frac{T_2}{T_1}$$

EXAMPLE 2

A gas has a volume of 500 cubic feet when the temperature is 45°F and the pressure is 20 pounds per square inch gauge (psig). If the temperature is changed to 90°F and the pressure stays the same, what will be the gas volume?

$$V_2 = 500 \frac{90 + 460}{45 + 460} = 544.6 \text{ ft}^3$$

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What would the pressure be for the gas above if the volume remains constant and the temperature changes from 45°F to 80°F? Atmospheric pressure is 14.7 psia.

$$P_2 = (20 + 14.7)\frac{90 + 460}{45 + 460} = 37.8 \text{ psia}$$

Boyle's and Charles' laws can be combined and expressed as:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

We can substitute known values in the above equation and solve for any one unknown.

Avogadro's Law. Avogadro's Law states that equal volumes of gases at the same temperature and pressure contain an equal number of molecules. From this law, we see that the weight of a volume of gas is a function of the weight of the molecules. In addition, at a certain volume, the gases weigh in pounds the numerical value of its molecular weight. This is known as the mol-volume. The mol-volume is 378.9 cubic feet for gases at 60°F and 14.73 psia. Table 3.7 lists the molecular weights for some of the compounds often associated with natural gas. The molecular weight for methane is 16.043. From the mol-volume explanation above it can be determined that 378.9 cubic feet of methane at 60°F and 14.73 psia weighs 16.043 pounds.

Ideal Gas Law. The Ideal Gas Law is the basic law for gas equations. It is used in many arrangements but often is written as:

$$PV = nRT$$

where P = Pressure of the gas
V = Volume of the gas
n = Number of pound-mols of the gas
R = Universal gas constant which varies depending on the pressure, volume, and temperature of the gas.

The number of pound-mols is equal to the weight of the gas divided by the molecular weight of the gas. Therefore, we write the Ideal Gas Law as:

$$PV = 10.722\frac{W}{M}T$$

where P = Pressure of the gas
V = Volume of the gas
W = Weight of the gas, pounds
M = Molecular weight of the gas
T = Temperature of the gas, Rankine.

The constant 10.722 is from the generally used value for the universal gas constant of 1544 when the pressure is in lb/ft^2 absolute.

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TABLE 3.6 General Formulas for Gas

Formulas	Symbols
Gas velocity: $V = \frac{748 Q_{Mcfh}}{d^2 P_2}$ Alternate method with gas temperature as a factor: $V = \frac{748 Q_{Mcfh}}{d^2 P_2}$	V = Velocity in feet per second D = Inside pipe diameter inches Q_{Mcfh} = Flow rate in *Mcfh* Q_{cfh} = Flow rate in *cfh* P_2 = Downstream pressure in psia T = Gas temperature in degrees Rankine
Pipeline pack for gas pipelines: $v = d^2 P_1 .378$ For $P_{avg} < 100$ $v = \frac{d^2 P_1 .378}{z}$ For $P_{avg} > 100$ $P_{avg} = \frac{2}{3}\left(P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right)$ $z = \frac{1}{\left[1 + \frac{P_{avg} 344400 (10)^{(1.785 Sg)}}{T^{3.825}}\right]^2}$	V = Pipeline volume in scf per 1000 feet D = Inside pipe diameter P_1 = Upstream pressure in psia P_2 = Downstream pressure in psia P_{avg} = Average pressure in the pipeline Z = Gas compressibility factor
Pipeline blowdown time: $BT_m = .0588 \frac{P_1^{1/3} Sg^{1/2} d^2 L F_c}{d_{blowdown}}$	BT_m = Blowdown time in minutes D = Inside pipe diameter $D_{blowdown}$ = Inside diameter of blowdown pipe inches P_1 = Upstream pressure in psia P_2 = Downstream pressure in psia Sg = Gas specific gravity L = Length of pipe section in miles F_c = Blowdown valve choke factor: Ideal nozzle: 1.0 Through gate: 1.6 Regular gate: 1.8 Regular lube plug: 2.0 Venturi lube plug: 3.2

The above equation also can be written in many forms to find an unknown. An often-used equation to find the weight of a quantity of gas is:

$$W = 0.0933 \frac{MVP}{T}$$

EXAMPLE 3

Find the weight of a gas in a 2000-cubic foot tank. The gas pressure is 200 psig at 90°F. The molecular weight of the gas is 16.535 and the barometric pressure

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TABLE 3.7 Molecular Weights

Compound	Molecular weight
Methane	16.043
Ethane	30.070
Propane	44.097
Butane	58.124
Pentane	72.151
Hexane	86.178
Heptane	100.205
Carbon dioxide	44.011
Nitrogen	28.016
Oxygen	32.00
Air	28.967

is 14.7 psia. This problem can be written as:

$$W = \frac{.0933 \times 16.535 \times 2{,}000 \times (200 + 14.7)}{90 + 460} = 1204 \text{ pounds}$$

Gas Pipeline Hydraulics

Several equations are used in gas pipeline hydraulics and selecting the proper equation is as important as doing the calculations correctly. Selecting the correct equation requires an understanding of the equations and parameters for the system being designed. Because of the assumptions made in each equation, a slight difference in the calculation can result when the equations are compared. The following section provides some of the frequently used equations and when they should be used.

Colebrook-White Equation. The Colebrook-White Equation is recommended for those who are not familiar with pipeline flow equations because it produces the greatest consistency of accuracy over a wide range of variables.

$$Q_h = 234.8 \frac{T_b}{P_b} \left(\frac{1}{f}\right)^{.5} \left(\frac{\Delta P}{G T_{avg} L_e Z}\right)^{.5} D^{2.5} E$$

where $\Delta P = P_1^2 - P_2^2$

and

$$Re \le 2000, \left(\frac{1}{f}\right)^{.5} = .25(Re)^{.5}$$

$$Re \ge 2000, \left(\frac{1}{f}\right)^{.5} = -4 \log_{10}(Re)^{.5} \left[\frac{k}{3.7D} + \frac{1.255}{Re}\left(\frac{1}{f}\right)^{.5}\right]$$

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Panhandle A Equation. This equation is best used for pipelines with Reynolds numbers in the range of 5×10^6 to 11×10^6. The average pipeline efficiency factor used in this equation is 92 percent. This number is based on actual empirical experience with the metered gas flow rates corrected to standard conditions. For larger diameter pipelines, the pipeline efficiency factor can be as high as 98 percent. With this equation, pipeline efficiency factors should be reduced for smaller pipe diameters. The Panhandle A Equation provides a reasonable approximation for partially turbulent flow. For fully turbulent flow, this equation does not produce accurate results. In the fully turbulent flow region, the Panhandle B Equation is recommended.

$$Q_d = 435.87\left(\frac{T_b}{P_b}\right)^{1.0778} D^{2.6182} E \left(\frac{\Delta P - (.0375 G \Delta H P_{avg}^2)}{\dfrac{T_{avg} Z}{G^{.8539} L_m T_{avg} Z}}\right)^{.5394}$$

where $\Delta P = P_1^2 - P_2^2$

and $P_{avg} = \dfrac{2}{3}\left[P_1 + P_2 - \dfrac{(P_1 P_2)}{P_1 + P_2}\right]$

$E = 1$ for new straight pipes without fittings or pipe diameter changes.

$E = 0.95$ for good pipe typically during the first 1-2 years of operation.

$E = 0.92$ for average operating conditions.

$E = 0.85$ for poor operating conditions.

Panhandle B Equation. This equation is best used for pipelines with Reynolds numbers in the range of 4×10^6 to 40×10^6. The Panhandle B Equation is used in the design of large diameter, high-pressure, long pipelines. The average pipeline efficiency factors are the same as the Panhandle A Equation. The Panhandle A Equation provides a reasonable approximation for turbulent flow conditions.

$$Q_d = 737\left(\frac{T_b}{P_b}\right)^{1.020} D^{2.53} E \left(\frac{\Delta P - (.0375 G \Delta H P_{avg}^2)}{\dfrac{T_{avg} Z}{G^{.961} L_m T_{avg} Z}}\right)^{.51}$$

where $\Delta P = P_1^2 - P_2^2$

and $P_{avg} = \dfrac{2}{3}\left[P_1 + P_2 - \dfrac{(P_1 P_2)}{P_1 + P_2}\right]$

Weymouth Equation. This is one of the older equations, but it still is used widely for natural gas distribution and gathering systems. The Weymouth Equation orig-

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inally was developed from data taken from low- to medium-pressure pipelines. The results obtained are conservative when the equation is used for higher-pressure pipelines. The Weymouth Equation typically is used for pipe diameters less than 6 inches in pressure ranges greater than 1.5 psig and less than 300 psig. This equation is not recommended for gas transmission through long pipelines.

$$Q_d = 433.5\left(\frac{T_b}{P_b}\right)\left[\frac{P_1^2 - P_2^2}{GL_m T_{avg} Z}\right]^{.5} D^{2.667} E$$

where $P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{(P_1 P_2)}{P_1 + P_2}\right]$

IGT-Improved Equation. This equation is used widely for natural gas distribution systems. When used for higher-pressure pipelines, the results obtained are conservative. The IGT Equation typically is used for pressure ranges between 1.5 and 100 psig. This equation is not recommended for gas transmission through long pipelines.

$$Q_h = 664\frac{T_b}{P_b}\frac{1}{\mu^{.111}}\left(\frac{\Delta P}{G^{.8} T_{avg} L_f}\right)^{.556} D^{2.667} E$$

Mueller-High-Pressure Equation. This equation is used in natural gas distribution systems with pressures above 1 psig.

$$Q_h = 2826\left(\frac{\Delta P}{G^{.739} L_f}\right)^{.575} D^{2.275} E$$

where $\Delta P = P_1^2 - P_2^2$

Mueller-Low-Pressure Equation. This equation is used in natural gas distribution systems with pressures below 1 psig.

$$Q_h = 735.4\frac{T_b P_{atm}^{.575}}{P_b \mu^{.15} G^{.425}}\left(\frac{\Delta h}{T_{avg} L_f}\right)^{.575} D^{2.725} E$$

where $\Delta h = h_1 - h_2$

Spitzglass Equation. This equation is best used for pipe diameters of 10 inches or less with pressures between 1.5 and 50 psig.

$$Q_h = 2209\frac{T_b}{P_b}\left(\frac{1}{f}\right)^{.5}\left(\frac{P_1^2 - P_2^2}{G T_{avg} L_f}\right)^{.5} D^{2.5} E$$

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where $$\frac{1}{f} = \left(\frac{1}{1 + \frac{3.6}{D} + 0.03D} \right)$$

Another popular version of the Spitzglass Equation often is used for natural gas distribution systems operating at 1 psig or less:

$$Q_h = 3550 \sqrt{\frac{\Delta h_w d^5}{GL_f + \left(\frac{3.6}{D} + 0.03D \right)}}$$

where Q_h = Flow rate, cubic feet per hour at 14.7 psia and 60°F
h = Static pressure head, inches of water.

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Source: PLASTIC PIPING HANDBOOK

CHAPTER 4
GENERAL DESIGN PROCEDURES

INTRODUCTION

This chapter covers the general design concepts that apply to various thermoplastic-piping systems. Regardless of the type of material being used, the effective use of thermoplastic piping systems depends on a thorough knowledge of pipe system design and the characteristics of the plastic material being used. When designing a thermoplastic piping system careful attention should be given to the unique properties of plastics and their effects on the piping system design, installation, and operation. In the majority of thermoplastic piping systems the main properties of concern are:

- Pressure limitations
- Temperature limitations
- Piping expansion and contraction

Thermoplastic piping systems are composed of various additives to a base resin or composition. Thermoplastics are characterized by their ability to be softened and reshaped repeatedly by the application of heat. Because of the slightly different compositions, the properties of plastic piping materials may vary between different manufacturers. As a result, designs and specifications need to address specific material requirements on a type and grade basis, which may need to be confirmed with the manufacturer.

DESIGN METHODOLOGY

The Design Analyses

All piping system designs are based on designing a piping system that will effectively and efficiently transport the required product. The design criteria for all

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piping applications are based on experience and applicable codes, standards, environmental requirements, and other parameters that may effect or constrain the work. An effective piping system design must include a methodical, step-by-step approach that gives proper consideration to the purpose of the piping system, how the system will be used, the conditions that the piping system will encounter, and the type of materials to be used.

Engineering calculations performed during the design analyses document the piping system design. Combined with the piping system criteria, the calculations define the process flow rates, system pressure and temperature, pipe strength requirements, pipe wall thickness, pipe stresses, and pipe support requirements. To be effective, design calculations should be clear, concise, and complete. The design calculations should document assumptions made, design data, and the sources of the data. All references (such as manuals, handbooks, and catalog cuts), alternate designs considered, and planned operating procedures should be included in the calculation records. Computer-aided design programs are helpful and time saving, but they should not be a substitute for the designer's understanding of the design process.

Another main task during the design is the development of an accurate piping system description. The piping system description should provide the function and major features of the system. The piping system description should contain the design bases, operating modes, control concepts, and both system and component performance ratings. Figure 4.1 lists the typical contents of a piping system description. The piping system description should provide enough information to develop:

- Process flow diagrams (PFDs)
- Piping and instrumentation diagrams P&IDs)
- And to obtain any required permits or approvals

Based on the design calculations and the piping system description, the last step of the design analyses is the development of the specifications for the piping system. Piping system specifications define the materials, fabrication, installation and construction, and service performance requirements of the materials to be used. There are two methods for identifying piping system specifications. One method identi-

Piping System Description
1. Function
2. Bases of Design Environmental Safety Performance Requirements Codes and Standards
3. Description General Overview System Operation Major Components

FIGURE 4.1 Piping system description.

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GENERAL DESIGN PROCEDURES

fies the specific materials or installation or construction practices to be followed, while the other is based on performance criteria. Performance specifications (as they are frequently called) list the required performance or capabilities but do not specify how the performance shall be achieved. The primary reason for performance-based specifications is to allow more vendors and manufacturers to compete for providing their products and services at the best cost or benefit to the client. There are some government contracts that require the use of performance-based specifications.

DRAWINGS

Plastic piping system drawings can take many forms depending on the application. For natural gas and water distribution systems they are primarily utility type drawings. For water, gas, and oil pipelines they are often in an alignment sheet format. However, regardless of the type of drawing they usually provide common information. Plastic piping system drawings normally include piping layout drawings, fabrication or detail drawings, instrumentation drawings, and pipe support drawings.

Process Flow Diagram (PFD)

PFD's are the schematic illustrations of the piping system description. PFD's show the relationship between the major piping system components. PFD's do not show pipe ratings or designations, minor piping systems, for example, sample lines or valve bypass lines; instrumentation or other minor equipment, isolation valves, vents, drains, etc. Figure 4.2 lists the typical items found on a PFD.

Piping and Instrumentation Diagram (P&ID)

P&ID's schematically illustrate the functional relationship of the piping, instrumentation, and system equipment components. P&ID's show all of the piping, including the intended physical sequence of branches, reducers, and valves, etc.;

Process Flow Diagrams
1. Major Equipment Symbols, Names, Identification
2. System Piping
3. Control Valves and Other Valves that Affect Operations
4. Piping System Interconnections
5. Piping System Ratings and Operational Variables Maximum, average, minimum flow Maximum, average, minimum pressure Maximum, average, minimum temperature
6. Type of Product Being Handled

FIGURE 4.2 Process flow diagrams.

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equipment; instrumentation and control. Figure 4.3 lists the typical items contained on a P&ID, and Figure 4.4 depicts a small and simplified P&ID.

DESIGN BASES

The bases of design are the physical and material parameters that are considered in the detailed design of a piping system to ensure a reasonable life cycle. The main considerations in the design of a piping system are loading and service condition and environmental factors. The basis of the design must be developed in order to perform the design calculations and prepare the drawings. Pre-design surveys are often required in the design of a new piping system and are a necessity for the renovation or expansion of existing systems. A site visit provides an overview of the project and the conditions at the location. Site visits are useful in obtaining the design requirements from the client and acquiring an overall sense of the project.

SERVICE CONDITIONS

Thermoplastic piping systems must be designed to provide reliable service under the service conditions it will encounter during the life of the system. The thermoplastic piping material must accommodate all combinations of loading situations that may occur such as pressure changes, temperature changes, thermal expansion and contraction, and other forces that may be present in the piping system. These conditions are referred to as the service conditions of the piping system. Service conditions are used to set design stress limits and may be defined or specified by applicable codes, or are determined based on the piping system description, site survey, and other design bases.

A main factor in the successful design of any thermoplastic piping system is determining and using the correct codes and standards. These are reviewed based on the project descriptions to determine and verify applicability. Codes and standards for the various plastic piping systems provide the required design criteria. These criteria are rules and regulations to follow when designing a plastic piping

Piping and Instrumentation Diagrams
1. Mechanical Equipment
2. All Valves
3. Instrumentation and designations
4. All Piping Sizes and Identification
5. All Miscellaneous Appurtenances including Vents, Drains, Special Fittings, Reducers, etc.
6. Direction of Flow
7. Class Change
8. Interconnections
9. Control Inputs and Outputs

FIGURE 4.3 Table of piping and instrumentation diagrams.

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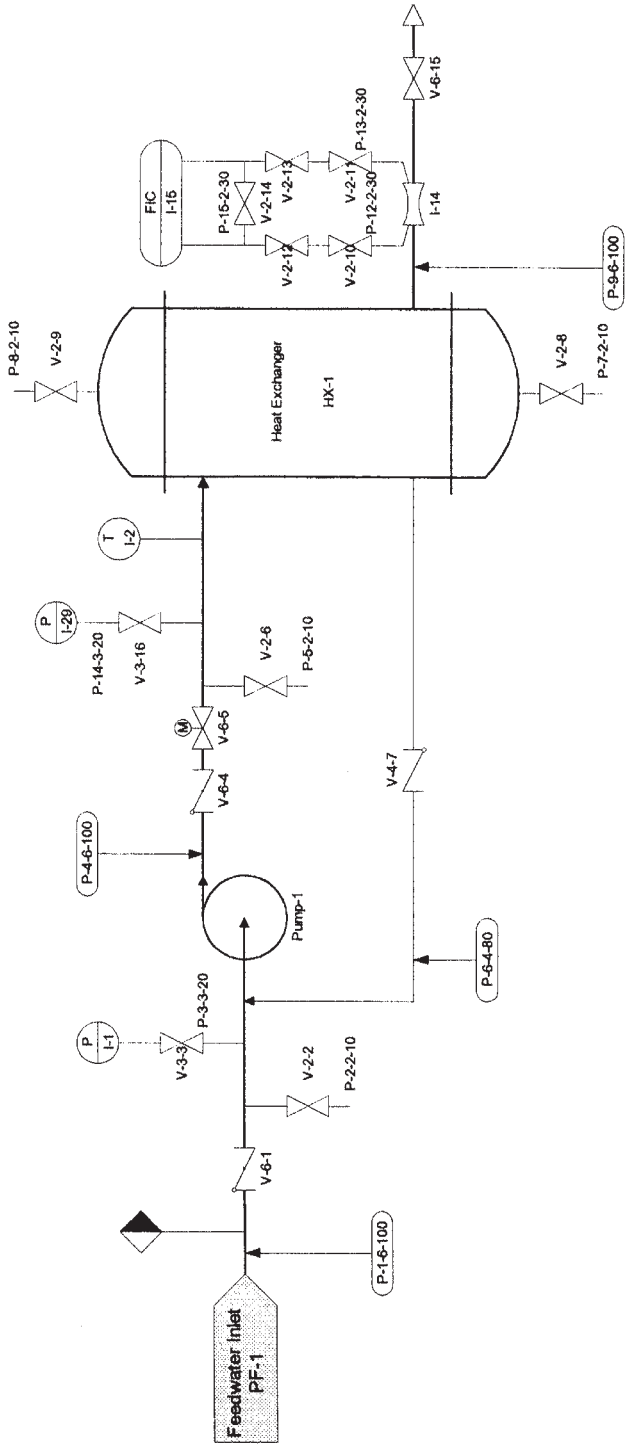

(A)

FIGURE 4.4 Piping and instrumentation diagrams.

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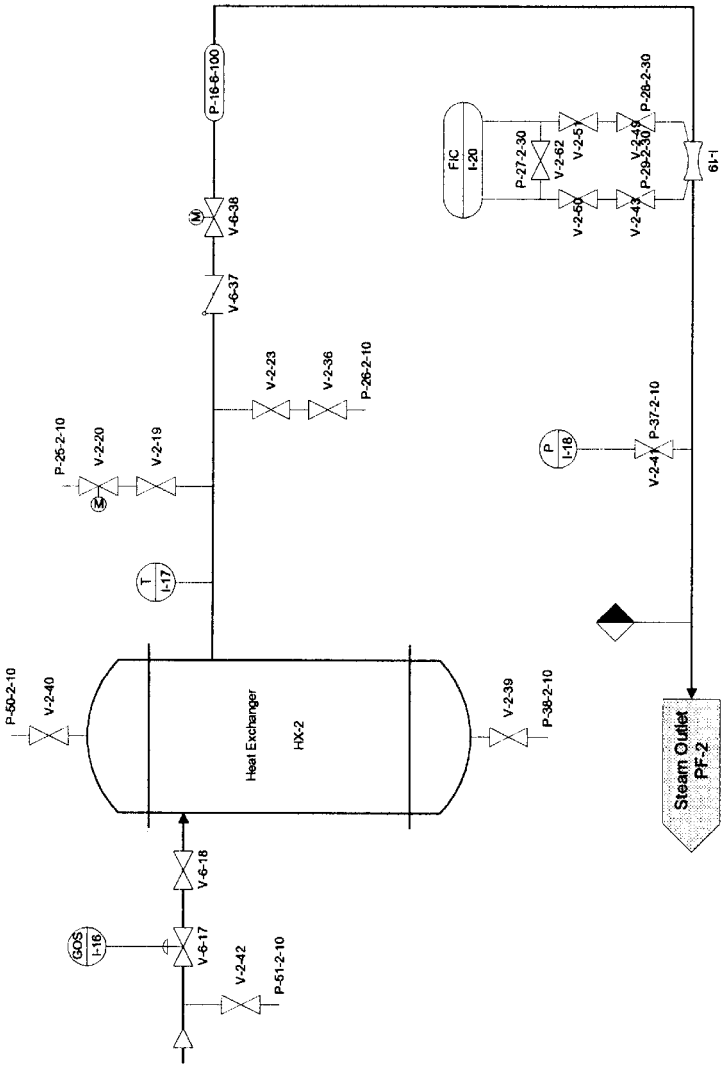

FIGURE 4.4 *(continued)* Piping and instrumentation diagrams.

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GENERAL DESIGN PROCEDURES

system. The following list is a sample of some of the parameters that are covered by design criteria found in piping codes:

- Allowable stresses and stress limits
- Allowable loads and load limits
- Materials
- Minimum pipe wall thickness or SDR
- Maximum deflection
- Seismic loads
- Thermal expansion

Standards provide the required design criteria and rules for components such as fittings, valves, and meters. The purpose of standards is to specify rules for the manufacturer of the components. Standards apply to both dimensions and performance of system components and are prescribed when specifying a plastic piping system.

LOADING CONDITIONS

The stresses on a piping system define the service conditions of the piping system and are a function of the loads on that system. The sources of these loads are internal pressure, piping system dead weight, differential expansion due to temperature changes, wind loads, and snow or ice loads. Loads on a piping system are classified as sustained or occasional loads.

Sustained Loads

Sustained loads are those loads that do not vary considerably over time and are constantly acting on the system. Examples of sustained loads are the pressures, both internal and external, acting on the system and the weight of the system. The weight of the system includes both that of the piping material and the operating fluid.

The sustained maximum system operating pressure is the basis for the design pressure. The design temperature is the liquid temperature at the design pressure. The minimum wall thickness of the pipe and the piping components pressure rating is determined by the design temperature and pressure. Although the design pressure is not to be exceeded during normal, steady state operations, short-term system pressure excursions in excess of the design pressures occur. These excursions are acceptable if the pressure increases over time and the time durations are within code-defined limits.

Piping codes provide design guidance and limits for design pressure excursions. If a code does not have an over-pressure allowance, transient conditions are

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accounted for within the system design pressure. A reasonable approach to overpressure conditions for applications without a specific design code is:

1. For transient pressure conditions that exceed the design pressure by 10 percent or less and act for less than 10 percent of the total operating time, neglect the transient and do not increase the design pressure
2. For transients whose magnitude or duration is greater than 10 percent of the design pressure or operating time, increase the design pressure to encompass the range of the transient

Dead weight is the dead load of a piping system or the weight of the pipe and system components. Dead weight generally does not include the weight of the system fluid. The weight of the fluid is normally considered an occasional load by code. For buried piping, dead weight is not a factor. However, a sustained load that is analyzed is the load from the earth above the buried piping. Because of the different potential for deformation, the effects of an earth load on flexible piping and rigid piping are analyzed differently.

Occasional Loads

Occasional loads are those loads that act on the system on an intermittent basis. Examples of occasional loads are those placed on the system from the hydrostatic leak test, seismic loads, and other dynamic loads. Dynamic loads are those from forces acting on the system, such as forces caused by water hammer, and the energy released by a pressure relief device. Another type of occasional load is caused by the expansion of the piping system material. An example of an expansion load is the thermal expansion of pipe against a restraint due to a change in temperature.

Wind load is a transient, live load (or dynamic load) applied to piping systems exposed to the effects of the wind. Obviously the effects of wind loading can be neglected for buried or indoor installation. Wind load can cause other loads, such as vibratory loads, due to reaction from a deflection caused by the wind.

Snow and ice loads are live loads acting on a piping system. For most heavy snow climates, a minimum snow load of 25 pounds per square foot (psf) is used in the design. In some cases, local climate and topography dictate a larger load. This is determined from ANSI A58.1, local codes, or by research and analysis of other data. Snow loads can be ignored for locations where the maximum snow is insignificant. Ice buildup may result from the environment, or from operating conditions.

The snow loads determined using ANSI A58.1 methods assume horizontal or sloping flat surfaces rather than rounded pipe. Assuming that snow lying on a pipe will take the approximate shape of an equilateral triangle with the base equal to the pipe diameter, the snow load is calculated with the following formula:

$$W_S = -nD_oS_L$$

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where W_S = design snow load acting on the piping, lb/ft
D_o = pipe (and insulation) outside diameter, in.
S_L = snow load, lb/ft^2
n = conversion factor, 0.083 ft/in

Ice loading information does not exist in data bases like snow loading. Unless local or regional data suggests otherwise, a reasonable assumption of 2 to 3 inches maximum ice accumulation is used to calculate an ice loading:

$$W_I = n_3 S_I t_I (D_o t_I)$$

where W_I = design ice load, lbs/ft
S_I = specific weight of ice, 56.1 lbs/ft^3
t_I = thickness of ice, in.
D_o = pipe (and insulation) outside diameter, in.
n^3 = conversion factor, 6.9×10 ft^2/in^2.

Seismic loads induced by earthquake activity are live (dynamic) loads. These loads are transient in nature. Appropriate codes are consulted for specifying piping systems that may be influenced by seismic loads. Seismic zones for most geographical locations can be found in American Water Works Association (AWWA) D110, AWWA D103, or CEGS 13080, Seismic Protection for Mechanical Electrical Equipment. ASME B31.3 (Chemical Plant and Petroleum Refinery Piping) requires that the piping is designed for earthquake induced horizontal forces using the methods of ASCE 7 or the Uniform Building Code.

Forces resulting from thermal expansion and contraction can cause loads applied to a piping system. A load is applied to a piping system at restraints or anchors that prevent movement of the piping system. Within the pipe material, rapid changes in temperature can also cause loads on the piping system resulting in stresses in the pipe walls. Finally, loads can be introduced in the system by combining materials with different coefficients of expansion.

Movements exterior to a piping system can cause loads to be transmitted to the system. These loads can be transferred through anchors and supports. An example is the settlement of the supporting structure. The settling movement transfers transient, live loads to the piping system.

Live loads can result from the effects of vehicular traffic and are referred to as wheel loads. Because aboveground piping is isolated from vehicle traffic, these live loads are only addressed during the design of buried piping. In general, wheel loads are insignificant when compared to sustained loads on pressure piping except when buried at "shallow" depths. The term shallow is defined based upon both site-specific conditions and the piping material. "However, as a rule, live loads diminish rapidly for laying depths greater than about four feet for highways and ten feet for railroads." Wheel loads are calculated using information in AASHTO H20 and guidance for specific materials such as AWWA C900 (PVC), and AWWA C950 (FRP).

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PIPING LAYOUT

The bases of design establish the factors that must be included in liquid process piping design. The preparation of the piping layout requires a practical understanding of complete piping systems, including material selections, joining methods, equipment connections, and service applications. The standards and codes previously introduced establish criteria for design and construction but do not address the physical routing of piping.

COMPUTER AIDED DRAFTING AND DESIGN

Computer based design tools, such as computer aided draft and design (CADD) software, can provide powerful and effective means to develop piping layouts. Much of the commercially available software can improve productivity and may also assist in quality assurance, particularly with interference analyses. Some CADD software has the ability to generate 3-dimensional drawings or 2-dimensional drawings, bills of material, and databases.

Piping Layout Design

System P&IDs, specifications, and equipment locations or layout drawings that are sufficiently developed to show equipment locations and dimensions, nozzle locations, and pressure ratings are needed to develop the piping layout. A completely dimensioned pipe routing from one point of connection to another with all appurtenances and branches as shown on the P&ID should be prepared.

Pipe flexibility is required to help control stress in liquid piping systems. Stress analysis may be performed using specialized software. Considerations that must be accounted for in routing piping systems in order to minimize stress include:

- Avoiding the use of a straight pipe run between two equipment connections or fixed anchor points
- Locate fixed anchors near the center of pipe runs so thermal expansion can occur in two directions
- Provide enough flexibility in branch connections for header shifts and expansions

In addition, the piping layout should utilize the surrounding structure for support where possible. Horizontal and parallel pipe runs at different elevations are spaced for branch connections and also for independent pipe supports.

Interferences with other piping systems, structural work, electrical conduit and cable tray runs, heating, ventilation and air conditioning equipment, and other process equipment not associated with the piping system of concern must be avoided.

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Insulation thickness must be accounted for in pipe clearances. To avoid interferences, composite drawings of the facility are typically used. This is greatly aided by the use of CADD software. However, as mentioned previously in this chapter, communications between engineering disciplines must be maintained as facilities and systems are typically designed concurrently though designs may be in different stages of completion.

Piping connections to pumps affect both pump operating efficiency and pump life expectancy. To reduce the effects, the design follows the pump manufacturer's installation requirements and the Hydraulic Institute Standards, 14th Edition. The project engineer should be consulted when unique piping arrangements are required.

Miscellaneous routing considerations are:

- Providing access for future component maintenance
- Pipe tracing access
- Hydrostatic test fill and drain ports
- Air vents for testing and startup operations

System operability, maintenance, safety, and accessibility are all considerations that are addressed in the design.

PRELIMINARY DESIGN DATA

Thermoplastic pipe material offers the advantages of flexibility, resiliency, and toughness. They differ from rigid plastic and steel pipe in some ways. Thermoplastic pipe is strong, extremely tough, and very durable. It can stand-alone or be considered as a portion of the environment. Thermoplastic piping installations act as a "system" within the environment and can gather additional strength from its surroundings and are responsive to changes in its physical environment.

There are many items to consider in the proper selection, design, and use of thermoplastic piping systems. Proper system design should give consideration to the following design criteria:

PIPELINE LIFE REQUIREMENTS

A determination should be made of the estimated "life" of the installed thermoplastic pipe system. When designing a city sewer system a life expectancy of 50 years is normal. A temporary, gravity-flow, mine slurry line may be in service only five years before operations are moved. A specialized chemical process plant may be obsolete or renovated in 15 to 20 years due to technology changes. The design parameters will vary depending on the intended use and desired life expectancy.

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FLOW REQUIREMENTS

Thermoplastic piping material provides a smooth pipe wall. Because it is smoother than many common pipe materials such as steel or concrete, it will transport more products in comparable pipe sizes. When compared to steel or concrete, smaller diameter thermoplastic pipe can carry an equivalent volumetric flow rate at the same pressure. This makes it ideal for relining pipes while maintaining identical flow capabilities.

Compatibility

There are many fluid property and chemical handling problems that can be solved with thermoplastic pipe. Because of its inherent chemical composition and structure, thermoplastic pipe does not react with most products being transported. There are only a very few strong chemicals which affect it. When considering chemical compatibility it is helpful to keep the following three factors in mind.

1. The chemical resistance of thermoplastic pipe is related to the chemical itself, the operating temperature and the concentration of the chemical
2. Strong oxidizing agents such as nitric acid, sulfuric acid, chlorine gas and liquid bromine are most aggressive and deserve special consideration
3. Permeation of the pipe wall is negligible for most products. However, aromatic hydrocarbon permeation rates should be reviewed

Specific Gravity. A close approximation should be made of the fluid's density or specific gravity for later use in flow calculations and/or installation calculations.

Viscosity. Some measure of the fluid's viscosity should be made or approximated over the system's operating temperature range. Flow and pressure calculations are related to this property. For example, if oil is the medium being pumped during summer and winter at constant pressure, the winter output (flow) decreases as its viscosity increases (i.e. gets colder).

Operating Pressures. When setting the design limits for a thermoplastic pipe system the engineer needs to consider the interdependence of the operating pressure, the operating temperature, the safety factor, and the expected life. Pipelines often do not operate at a stable pressure and the engineer needs to estimate the operating pressure range. The design should consider the highest long term operating pressure with recognition given to the additional safety factor gained at lower operating pressures.

Surge Pressures (Water Hammer). Special consideration should be given to pressurized systems with valves or shut-offs. The time of operation of a valve

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may convert the mass inertia of the flowing fluid into a high static head on the pressure side of the pipeline. Because of the flexibility, resilience and toughness of thermoplastic pipe it can absorb significant surge pressures.

Solids Content. Thermoplastic pipe is often used to convey slurry mixtures in processing pipelines and waste conveying pipelines. The design in these applications should consider the slurry solids content, its particle structure, abrasiveness, size distribution, and net specific gravity.

Fluid Temperature Range. The temperature of the fluid being conveyed has an effect on the service capability of thermoplastic pipe. Thermoplastic piping loses stiffness and tensile strength as temperature increases. As temperature rises, the normal operating pressure of the pipe should be derated or a heavier wall pipe should be specified to hold the same pressure at higher temperatures.

As the temperature decreases, the pipe gains strength. The pipe may be designed to hold rated pressure at 73.4°F with recognition of a greater safety factor at lower temperatures. Allowances for thermal expansion and contraction should be engineered into any installation based upon the fluid or environmental temperature.

Environmental Temperature Range. The design of thermoplastic pipe systems must take into consideration the environmental conditions. Piping system in the hot climates with high daily temperatures obviously must differ from installations in cold regions below the frost line. The system engineer needs to consider both the fluid temperature and environmental temperature when determining which SDR to specify, as well as in compensating for thermal expansion and contraction.

INSTALLATION CONSIDERATIONS

When designing a thermoplastic piping system, the designer should categorize each installation. Each installation requires selection of the proper SDR to support the external earth or traffic loads imposed on the pipe. Simultaneously, earth compaction factors should be specified for burial installations to ensure that the true earth and traffic loads do not exceed the system design limits. Some important factors to consider for each installation are:

Loads on Supported Pipelines. Supports must be spaced frequent enough to prevent the pipeline from any sag caused by the weight of the pipe and contents. The proper spacing of supports also allow for control or restraint of thermal expansion.

Loads on Exposed Pipelines. Chapter 5 will fully cover aboveground piping installation. Pipelines installed overland are exposed to numerous hazards. Changes in temperature causes the pipe to contract or expand as all materials do. The pipe

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movement caused by this thermal movement should be controlled by such means as snaking, anchoring or shallow trenching. This will prevent abrasion due to movement as well as possible kinking. When the temperature increases, the pressure rating of the pipe is decreased. When the temperature decreases, the safety factor on pipe pressure is increased.

Loads on Buried Pipelines. When designing buried thermoplastic piping system the design must consider the earth load, loads imposed by settling, loads imposed by variable water tables, etc.

Live Traffic Loads. Traffic operating over a buried pipeline (or even near a pipeline) causes the earth to move under its weight. This ever-so-slight movement is a dynamic load transfer from the vehicle to the ground. The heavier the vehicle, the greater the load transfers. To distribute and reduce the load on the pipe, it can be buried deeper (within limits) and/or located farther from traffic. The stress on the pipe may also be reduced by increasing the soil compaction (density) or eliminated by conducting it through a casing pipe. The system designer should review the various traffic weight classes, soil compaction factors and the associated stress presented in the design section.

When designing a thermoplastic piping system it is often justified to select a pipe size, wall thickness or SDR other than that determined through an engineering analysis. Selecting a thicker wall is often specified in slurry applications to lengthen the service life and maintain the pipe pressure rating as it wears. Upgrading may also be performed as a safeguard against unknowns such as variable operating conditions, system abuse, suspicious soil conditions, etc. The designer may select the next thicker wall and higher pressure rating to reduce hoop stress and increase the functional factor of safety. If a piping installation offers a high risk of damage and serious economic consequences or the public safety is involved, the engineers best judgment may be to incorporate additional safety factors in the pipeline design.

DESIGN CONSIDERATIONS FOR PLASTIC PIPING SYSTEMS

Thermoplastic piping systems, commonly referred to as plastic piping systems, are composed of various additives to a base resin or composition. Thermoplastics are characterized by their ability to be softened and reshaped repeatedly by the application of heat. Figure 4.5 lists the chemical names and abbreviations for a number of thermoplastic piping materials. Because of the slightly different formulations, properties of plastic piping materials (for example, polyvinyl chloride/PVC) may vary from manufacturer to manufacturer. Therefore, designs and specifications need to address specific material requirements on a type or grade basis, which may have to be investigated and confirmed with manufacturers.

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GENERAL DESIGN PROCEDURES

Abbreviation	Chemical Name
ABS	Acrylonitrile-Butadiene-Styrene
CPVC	Chlorinated Poly(Vinyl Chloride)
ECTFE	Ethylene-Chlorotrifluoroethylene
ETFE	Ethylene-Tetrafluoroethylene
FEP	Perfluoro(Ethylene-Propylene) Copolymer
PE	Polyethylene
PFA	Perfluoro(Alkoxyalkane) Copolymer
PP	Polypropylene
PTFE	Polytetrafluoroethylene
PVC	Poly(Vinyl Chloride)
PVDC	Poly(Vinylidene Chloride)
PVDF	Poly(Vinylidene Fluoride)

FIGURE 4.5 Abbreviations for thermoplastic materials.

Corrosion

Unlike metallic piping, thermoplastic materials do not display corrosion rates. That is, the corrosion of thermoplastic materials is dependent totally on the material's chemical resistance rather than an oxide layer, so the material is either completely resistant to a chemical or it deteriorates. This deterioration may be either rapid or slow. Plastic piping system corrosion is indicated by material softening, discoloration, charring, embrittlement, stress cracking (also referred to as crazing), blistering, swelling, dissolving, and other effects. Corrosion of plastics occurs by the following mechanisms:

- Absorption
- Solvation
- Chemical reactions such as oxidation (affects chemical bonds), hydrolysis (affects ester linkages), radiation, dehydration, alkylation, reduction, and halogenation (chlorination)
- Thermal degradation which may result in either depolymerization or plasticization
- Environmental-stress cracking (ESC) which is essentially the same as stress-corrosion cracking in metals
- UV degradation
- Combinations of the above mechanisms

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If reinforcing is used as part of the piping system, the reinforcement is also a material that is resistant to the fluid being transported. Material selection and compatibility review should consider the type and concentration of chemicals in the liquid, liquid temperature, duration of contact, total stress of the piping system, and the contact surface quality of the piping system.

Operating Pressures and Temperatures

The determination of maximum steady state design pressure and temperature is similar to that described for metallic piping systems. However, a key issue that must be addressed relative to plastic piping systems is the impact of both minimum and maximum temperature limits of the materials of construction.

Sizing

One of the basic principles of designing and specifying thermoplastic piping systems for liquid process piping pressure applications is that the short and long term strength of thermoplastic pipe decreases as the temperature of the pipe material increases.

Thermoplastic pipe is pressure rated by using the International Standards Organization (ISO) rating equation using the Hydrostatic Design Basis (HDB) as contained in ASTM standards and Design Factors (DF's). The use of DF's is based on the specific material being used and specific application requirements such as temperature and pressure surges. The following is the basic equation for internal hydraulic pressure rating of thermoplastic piping:

$$P_R = 2(HDS)\left(\frac{t}{D_m}\right)$$

where P_R = pipe pressure rating, psi
t = minimum wall thickness, in.
D_m = mean diameter, in.
$HDS = (HDB)(DF)$

It should not be assumed that thermoplastic fittings labeled with a pipe schedule designation would have the same pressure rating as pipe of the same designation. A good example of this is contained in ASTM D 2466 and D 2467, which specify pressure ratings for PVC schedule 40 and 80 fittings. These ratings are significantly lower than the rating for PVC pipe of the same designation. For thermoplastic pipe fittings that do not have published pressure ratings information similar to ASTM standards, the fitting manufacturer shall be consulted for fitting pressure-rating recommendations.

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GENERAL DESIGN PROCEDURES

Joining

Common methods for the joining of thermoplastic pipe for liquid process waste treatment and storage systems are contained in Figure 4.6. In selecting a joining method for liquid process piping systems, the advantages and disadvantages of each method are evaluated and the manner by which the joining is accomplished for each liquid service is specified. Recommended procedures and specification for these joining methods are found in codes, standards and manufacturer procedures for joining thermoplastic pipe. Figure 4.7 lists applicable references for joining thermoplastic pipe.

Thermal Expansion

When designing a piping system where thermal expansion of the piping is restrained at supports, anchors, equipment nozzles, and penetrations, large thermal stresses and loads must be analyzed and accounted for within the design. The system PFDs and P&IDs are analyzed to determine the thermal conditions or modes to which the piping system will be subjected during operation. Based on this analysis, the

Joining Method	ABS	PVC	CPVC	PE	PP	PVDF
Solvent Cementing	X	X	X			
Heat Fusion				X	X	X
Threading*	X	X	X	X	X	X
Flanged Connectors**	X	X	X	X	X	X
Grooved Joints***	X	X	X	X	X	X
Mechanical Compression****	X	X	X	X	X	X
Elastomeric Seal	X	X	X	X	X	X
Flaring				X		

FIGURE 4.6 Thermoplastic joining methods.

Reference	Key Aspects of Reference
ASTM D 2657	Recommended practice for heat fusion.
ASTM D 2855	Standard practice for solvent cementing PVC pipe and fittings.
ASTM D 3139	Elastomeric gasketed connections for pressure applications.
ASTM F 1290	Recommended practice for electrofusion.

FIGURE 4.7 Thermoplastic joining methods.

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design and material specification requirements from an applicable standard or design reference are followed in the design.

A basic approach to assess the need for additional thermal stress analysis for piping systems includes identifying operating conditions that will expose the piping to the most severe thermal loading conditions. Once these conditions have been established, a free or unrestrained thermal analysis of the piping can be performed to establish location, sizing, and arrangement of expansion loops, or expansion joints (generally, bellows or slip types).

If the application requires the use of a bellow or piston joint, the manufacturer of the joint shall be consulted to determine design and installation requirements. When expansion loops are used, the effects of bending on the fittings used to install the expansion loop are considered. Installation of the loop should be performed in consultation with the fitting manufacturer to ensure that specified fittings are capable of withstanding the anticipated loading conditions, constant and cyclic, at the design temperatures of the system. Terminal loadings on equipment determined from this analysis can then be used to assess the equipment capabilities for withstanding the loading from the piping system. It should also be noted that this termination analysis at equipment and anchor terminations should consider the movement and stress impacts of the "cold" condition.

No rigid or restraining supports or connections should be made within the developed length of an expansion loop, offset, or bend. Concentrated loads such as valves should not be installed in the developed length. Piping support guides should restrict lateral movement and should direct axial movement into the compensating configurations. Calculated support guide spacing distances for offsets and bend should not exceed recommended hanging support spacing for the maximum temperature. If that occurs, distance between anchors will have to be decreased until the support guide spacing distance equals or is less than the recommended support spacing. Use of the rule of thumb method or calculated method is not recommended for threaded Schedule 80 connections. Properly cemented socket cement joints should be utilized.

Expansion loops, offsets and bends should be installed as near as possible at the mid point between anchors.

Values for expansion joints, offsets, bends and branches can be obtained by calculating the developed length from the following equation:

$$L = n_1 \frac{3ED_o\sqrt{e^{1\backslash 2}}}{S}$$

where L = developed length, ft.
n_1 = conversion factor, ½ ft/in.
E = tensile modulus of elasticity, psi
D_o = pipe outer diameter, in.
e = elongation due to temperature rise, in.
S = maximum allowable stress, psi

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In determining the elongation due to temperature rise information from the manufacturer on the material to be used should be consulted. For example, the coefficient of expansion is 3.4×10^{-5} in/in/F) for Type IV Grade CPVC and 2.9×10^{-5} in/in/F) for Type I Grade I PVC. Other sources of information on the thermal expansion coefficients are available from the plastic pipe manufacturers.

PVC and CPVC pipe does not have the rigidity of metal pipe and can flex during expansion, especially with smaller diameters. If expansion joints are used, axial guides should be installed to ensure straight entrance into the expansion joint, especially when maximum movement of the joint is anticipated. Leakage at the seals can occur if the pipe is cocked. Independent anchoring of the joint is also recommended for positive movement of expansion joints.

PIPING SUPPORT AND BURIAL

Support for thermoplastic pipe follows the same basic principles as metallic piping. Spacing of supports is crucial for plastic pipe. Plastic pie will deflect under load more than metallic pipe. Excessive deflection will lead to structural failure. Therefore, spacing for plastic is closer than for metallic pipe. Valves, meters, and fittings should be supported independently in plastic pipe systems, as in metallic systems.

In addition, plastic pipe systems are not located near sources of excessive heat. The nature of thermoplastic pipe is that it is capable of being repeatedly softened by increasing temperature, and hardened by decreasing temperature. If the pipe is exposed to higher than design value ambient temperatures, the integrity of the system could be compromised.

Contact with supports should be such that the plastic pipe material is not damaged or excessively stressed. Point contact or sharp surfaces are avoided as they may impose excessive stress on the pipe or otherwise damage it.

Support hangers are designed to minimize stress concentrations in plastic pipe systems. Spacing of supports should be such that clusters of fittings or concentrated loads are adequately supported. Valves, meters, and other miscellaneous fittings should be supported exclusive of pipe sections.

Supports for plastic pipe and various valves, meters, and fittings, should allow for axial movement caused by thermal expansion and contraction. In addition, external stresses should not be transferred to the pipe system through the support members. Supports should allow for axial movement, but not lateral movement. When a pipeline changes direction, such as through a 90° elbow, the plastic pipe should be rigidly anchored near the elbow.

Plastic pipe systems should be isolated from sources of vibration such as pumps and motors. Vibrations can negatively influence the integrity of the piping system, particularly at joints. Support spacing for several types of plastic pipe are found in Figures 4.8, 4.9, and 4.10. Spacing is dependent upon the temperature of the fluid being carried by the pipe.

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Nominal Pipe Size, inch	Maximum Support Spacing, ft at 60°F	Maximum Support Spacing, ft at 80°F	Maximum Support Spacing, ft at 100°F	Maximum Support Spacing, ft at 120°F	Maximum Support Spacing, ft at 140°F*
1	6.0	5.5	5.0	3.5	3.0
1.5	6.5	6.0	5.5	3.5	3.5
2	7.0	6.5	6.0	4.0	3.5
3	8.0	7.5	7.0	4.5	4.0
4	9.0	8.5	7.5	5.0	4.5
6	10.0	9.5	9.0	6.0	5.0
8	11.0	10.5	9.5	6.5	5.5
10	12.0	11.0	10.0	7.0	6.0
12	13.0	12.0	10.5	7.5	6.5
14	13.5	13.0	11.0	8.0	7.0

Note: The above spacing values are based on test data developed by the manufacturer for the specific product and continuous spans. The piping is insulated and is full of liquid that has a specific gravity of 1.0.
* The use of continuous supports or a change of material (e.g., to CPVC) is recommended at 140°F.

FIGURE 4.8 Support spacing for schedule 40 PVC pipe. Maximum support spacing in feet at various temperatures.

Nominal Pipe Size, inch	Maximum Support Spacing, ft at 68°F	Maximum Support Spacing, ft at 104°F	Maximum Support Spacing, ft at 140°F	Maximum Support Spacing, ft at 176°F
1	3.5	3.0	3.0	2.5
1.5	4.0	3.0	3.0	3.0
2	4.5	4.0	3.0	3.0
3	5.5	4.0	4.0	3.5
4	6.0	5.0	4.0	4.0
5	7.0	6.0	5.0	4.5

Note: The above spacing values are based on test data developed by the manufacturer for the specific product and continuous spans. The piping is insulated and is full of liquid that has a specific gravity of 1.0.

FIGURE 4.9 Support spacing for schedule 80 PVDF pipe. Maximum support spacing in feet at various temperatures. *(Source: Asahi/America, Piping Systems Product Bulletin P-97/A)*

The determining factor to consider in designing buried thermoplastic piping is the maximum allowable deflection in the pipe. The deflection is a function of the bedding conditions and the load on the pipe. The procedure for determining deflection is as follows:

$$\%\text{deflection} = \frac{100Y}{D_o}$$

where: Y = calculated deflection
D_o = outer pipe diameter, in.

$$Y = \frac{K_x d_e w}{0.149(PS).061(E)}$$

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Nominal Pipe Size, inch	Maximum Support Spacing, ft at 73°F	Maximum Support Spacing, ft at 100°F	Maximum Support Spacing, ft at 120°F	Maximum Support Spacing, ft at 140°F	Maximum Support Spacing, ft at 160°F	Maximum Support Spacing, ft at 180°F
1	6.0	6.0	5.5	5.0	3.5	3.0
1.5	7.0	6.5	6.0	5.5	3.5	3.0
2	7.0	7.0	6.5	6.0	4.0	3.5
3	8.0	8.0	7.5	7.0	4.5	4.0
4	8.5	8.5	8.5	7.5	5.0	4.5
6	10.0	9.5	9.0	8.0	5.5	5.0
8	11.0	10.5	10.0	9.0	6.0	5.5
10	11.5	11.0	10.5	9.5	6.5	6.0
12	12.5	12.0	11.5	10.5	7.5	6.5

Note: The above spacing values are based on test data developed by the manufacturer for the specific product and continuous spans. The piping is insulated and is full of liquid that has a specific gravity of 1.0.

FIGURE 4.10 Support spacing for schedule 80 CPVC pipe. Maximum support spacing in feet at various temperatures.

where Y = calculated deflection
K_x = bedding factor (see Figure 4.11)
d_e = deflection lag factor (see Figure 4.12)
w = weight per length of overburden, lb/in.
PS = pipe stiffness, psi
E = soil modulus, psi (see Figure 4.13)

$$w = \frac{HD_o\gamma}{144}\pi D_o$$

where w = weight per length of overburden, lb/in.
H = height of cover, ft.
D_o = outer pipe diameter, in.
γ = density of soil lb/ft^3
π = soil overburden pressure, psi

$$PS = \frac{EI_a}{.149R^3}$$

where PS = pipe stiffness, psi
E = modulus of elasticity of pipe, psi
I_a = area moment of inertia per unit length of pipe, in4/in
R = mean radii of pipe, psi

$$R = \frac{D_o t}{2}$$

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where R = mean radii of pipe, psi
D_o = outer pipe diameter, in.
t = average wall thickness, in

$$I_a = \frac{t^3}{12}$$

where I_a = area moment of inertia per unit length of pipe, in^4/in
t = average wall thickness, in.

Proper excavation, placement, and backfill of buried plastic pipe is crucial to the structural integrity of the system. It is also the riskiest operation, as a leak in the system may not be detected before contamination has occurred. A proper bed, or trench, for the pipe is the initial step in the process. In cold weather areas, underground pipelines should be placed no less than one foot below the frost line. The trench bottom should be relatively flat, and smooth, with no sharp rocks that could damage the pipe material. The pipe should be bedded with a uniformly graded material that will protect the pipe during backfill. Typical installations use an American Association of State Highway Transportation Officials (AASHTO) #8 aggregate, or pea-gravel for six inches below and above the pipe. These materials can be dumped in the trench at approximately 90-95 percent Proctor without mechanical compaction. The remainder of the trench should be backfilled with earth, or other material appropriate for surface construction, and compacted according to the design specifications.

Type of Installation	K_x
Shaped bottom with tamped backfill material placed at the sides of the pipe, 95% Proctor density or greater	0.083
Compacted coarse-grained bedding and backfill material placed at the side of the pipe, 70-100% relative density	0.083
Shaped bottom, moderately compacted backfill material placed at the sides of the pipe, 85-95% Proctor density	0.103
Coarse-grained bedding, lightly compacted backfill material placed at the sides of the pipe, 40-70% relative density	0.103
Flat bottom, loose material placed at the sides of the pipe (not recommended); <35% Proctor density, <40% relative density	0.110

FIGURE 4.11 Bedding factor, K_x.

Installation Condition	d_c
Burial depth <5 ft. with moderate to high degree of compaction (85% or greater Proctor, ASTM D 698 or 50% or greater relative density ASTM D-2049)	2.0
Burial depth <5 ft. with dumped or slight degree of compaction (Proctor >85%, relative density >40%)	1.5
Burial depth >5 ft. with moderate to high degree of compaction	1.5
Burial depth >5 ft. with dumped or slight degree of compaction	1.25

FIGURE 4.12 Deflection lag factor, d_c.

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Soil Type and Pipe Bedding Material	Dumped	Slight <85% Proctor >40% relative density	Moderate 85-95% Proctor 40-70% relative density	High >90% Proctor >70% relative density
Fine-grained soils (LL>50) with medium to high plasticity CH, MH, CH-MH	No data available – consult a soil engineer or use E = 0	No data available – consult a soil engineer or use E = 0	No data available – consult a soil engineer or use E = 0	No data available – consult a soil engineer or use E = 0
Fine-grained soils (LL<50) with medium to no plasticity CL, ML, ML-CL, with 25% coarse-grained particles	50	200	400	1000
Fine-grained soils (LL<50) with no plasticity CL, ML, ML-CL, with >25% coarse-grained particles	100	400	1000	2000
Coarse-grained soils with fines GM, GC, SM, SC contains >12% fines	100	400	1000	2000
Coarse-grained soils with little or no fines GW, SW, GP, SP contains <12% fines (or any borderline soil beginning with GM-GC or GC-SC)	200	1000	2000	3000
Crushed rock	1000	3000	3000	3000

Notes: LL = liquid limit

FIGURE 4.13 Values of E' Modulus of soil reaction for various soils. E for degree of compaction of bedding. lbs/ft^2. *(Source: AWWA C900, Table A.4)*

GENERAL DESIGN CONSIDERATIONS

The design of a thermoplastic piping system is a straightforward process. It is a repetitive procedure that requires attention to detail and the exercise of some judgment. Each design can be different and operating conditions are diverse. Regardless of design criteria, the design process is relatively simple. Basically, it involves the selection of a pipe; sized to transport the required flow and the selection of a pipe wall thickness adequate handle the system pressure safely. The system pressure and temperature determine the pipe's wall thickness. Flow velocity and pressure drop determine the pipes inside diameter and the system flow rate. The pipe selection process is a repetitive procedure which matches and balances pipe I.D. and wall thickness in order to optimize pressure and flow capabilities at a reasonable cost.

The following items should be evaluated when designing a specific thermoplastic piping system.

- Consider service life requirements
- Consider the pipe inside diameter required to meet flow requirements

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- Consider the pipe and wall thickness required to meet pressure requirements
- Work with the pipe size and wall thickness until the flow and pressure in the pipe selected are acceptable for both
- Consider the external "Earth Load and Live Loads"
- Adjust pipe wall thickness as required for external loads
- Consider rerating the pipe based upon the environmental or operating temperature
- Review the final pipe size and wall thickness to meet flow, pressure and external load requirements at a given temperature and system life expectancy

SYSTEM FLOW REQUIREMENTS

Thermoplastic pipe has an exceptionally smooth pipe wall. This results in its excellent flow capacity. Thermoplastic pipes have less drag, less tendency for flow turbulence, no corrosion, and are less susceptible to deposits or bacterial growth. Because of its excellent flow properties, a smaller diameter pipe can often be specified to carry a given volume when compared with steel, cast iron or concrete.

Pressurized Full Flow

Many equations are available to show the relationship between fluid flow and pressure drop in a given pipeline. The equations typically involve a friction factor that is dependent on the pipe materials. Darcy-Weisbach and Hazen-Williams are commonly used equations.

Initial Flow Estimates. If the inside diameter of a particular pipe size is known, the flow rate, in gallon per minute, can be calculated by assuming a nominal velocity.

$$Q = 2.449VD^2$$

where Q = Gallons per minute
V = Velocity (ft./sec.)
D = *I. D.* (inches)

By knowing the required gallon per minute and assuming a nominal flow velocity we can calculate the pipe diameter or velocity.

$$D = .639\sqrt{\frac{Q}{V}}$$

$$V = .408\left(\frac{Q}{D^2}\right)$$

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By using these three formulas we can establish a required range for the pipe diameter, flow rate, and flow velocity.

The designer will need to exercise judgment in the selection of pipe sizes to best meet the design parameters and goals. The following items can prove helpful:

- For a given flow rate, a larger diameter pipe will have a lower velocity and a lower pressure drop
- For a given flow rate, a smaller diameter pipe will have higher velocity and a higher pressure drop
- Higher velocity in larger diameter pipes produced less frictional head loss when compared to the same velocity in a smaller pipe
- For laminar flow, the loss in pressure through a pipe is inversely proportional to the fourth power of the pipe inside diameter
- For turbulent flow, the loss in pressure through a pipe is directly proportional to the square of the flow rate and inversely proportional to the fifth power of the inside diameter

PRESSURE LOSS IN FITTINGS

Valves, fittings, and other piping system components in the thermoplastic piping system result in additional pressure loss within the piping system. The designer should consider the additional pressure losses. There are several methods for calculating the pressure loss caused by piping system components that are available in many fluid flow and piping handbooks. Listed below are various common thermoplastic piping system components and the associated pressure loss through the fitting expressed as an equivalent length of straight pipe in terms of diameters. The inside diameter (in feet) multiplied by the equivalent length diameters gives the equivalent length (in feet) of pipe. This equivalent length of pipe is added to the total footage of the piping system when calculating the total system pressure drop.

These equivalent lengths should be considered an approximation suitable for most installations.

Fabricated Fitting	Equiv. Length
Running Tee	20 D
Branch Tee	50 D
90(Fabricated Elbow	30 D
60(Fabricated Elbow	25 D
45(Fabricated Elbow	18 D
45(Fabricated Wye	60 D
Conventional Globe Valve (Full Open)	350 D
Conventional Angle Valve (Full Open)	180 D
Conventional Wedge Gate Valve (Full Open)	15 D
Butterfly Valve (Full Open)	40 D

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Once the proper pipe sizes have been chosen based upon the flow requirements, the following items should be considered:

- The total system pressure drop should not exceed the pressure rating of the thermoplastic pipe selected
- The pump pressure should exceed the system pressure drop, but should not exceed the pressure rating of the pipe selected

GRAVITY FLOW

Gravity Flow systems are common in industrial and municipal waste and sewer lines as well as water and slurry pipelines. Gravity flow systems may operate under full flow or partially full conditions. Because of the superior wall smoothness and excellent flow characteristics of thermoplastic pipe, they are an excellent choice for gravity flow piping systems.

The designer can specify smaller pipe diameters to support the required flow resulting in reduced system costs. In addition, the maintenance costs for thermoplastic piping systems are less than metal systems. The reduced operating costs and reliability of thermoplastic piping systems often result in improved service.

Full Flow. There are three key items required to properly select and size thermoplastic piping for a full flow gravity system:

1. GPM flow-rate requirements
2. The slope of the pipeline
3. Selection of an appropriate pipe inside diameter

For a full flow condition, the gallon per minute flow rate can be calculated using the Manning equation as follows:

$$Q = 98.3ARh^{2/3}S^{1/2}$$

where Q = Flow in gpm
Rh = Hydraulic radius (ID)(4)(inches)
S = Slope (ft./foot)
A = Cross sectional area of pipe I.D. in sq. inches
V = Velocity (ft./sec)
ID = Inside diameter in inches

(Note: Above formula includes $\eta = .009$)

The velocity can be calculated by:

$$V = 31.5R_h^{2/3}S^{1/2} = \frac{.320Q}{A}$$

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The inside diameter by:

$$ID = \sqrt[2.67]{\frac{.03279Q}{S^{1/2}}}$$

And the slope by:

$$S = \frac{.001075Q^2}{ID^{5.34}}$$

Partial Flow. Gravity pipelines have a higher liquid flow capacity when flowing at 85-95 percent full than when 100 percent full. This is caused by the effect of reduced friction due to the liquid's contact with less pipe wall surface. The following illustrates the changes in velocity and flow capacity when compared to full flow.

Flow Capacity of Partially Full Pipes

% Full	Velocity (% of full)	Flow Capacity (% of full)
100	100	100
95	111	106.3
90	115	107.3
80	116	98
70	114	84
60	108	67
50	100	50
40	88	33
30	72	19
25	65	14
20	56	9
10	36	3

For gravity partial flow pipelines, the GPM flow rate can be calculated through the use of the Manning equation as follows:

$$Q = 98.3AR_h^{2/3}S^{1/2}$$

where Q = Flow in gpm
A = Pipeline cross-sectional flow area in square inches
R_h = Hydraulic Radius in inches
R_h = Flow area in sq. inches divided by wetted perimeter in inches
S = Slope or gradient (ft/ft)
V = Velocity in ft/sec

$$V = .320\left(\frac{Q}{A}\right)$$

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It is normal practice to consider a partially full gravity flow pipeline as a full flow pipeline of a smaller, "equivalent" diameter. The "equivalent" diameter matches all the hydraulic characteristics of the larger, partial flow gravity pipeline. The velocity, GPM flow rate and slope are identical in each case. The equivalent diameter is four times the hydraulic radius. The hydraulic radius for partial flow gravity pipelines is defined as the ratio of the cross-sectional flow area divided by the wetted perimeter.

SLIPLINING FLOW CAPACITY

Thermoplastic piping, most often PE pipe, is frequently used for slip lining of sewers and waste handling systems. Determining the proper pipe size for sliplining is done by determining the maximum size of liner that can be inserted into the existing line and the flow required through the new liner. Manning's formula can be used to determine the flow of sewage. With the Manning Formula, a relationship of pipe diameters is established so that the liner size may be calculated that is required to restore the sewer to its original capacity. A good rule of thumb in sizing the slipline pipe is to allow 10 percent of the diameter as a clearance gap between the larger pipe and the liner.

Slurry Critical Flow

Thermoplastic piping has demonstrated its superior abrasion resistance when compared to conventional materials and field tests have demonstrated that thermoplastic piping outlast steel piping as much as 3 to 1. This section discusses some of the major design topics to be considered when designing a slurry pipeline. The designer is encouraged to pursue an in-depth study of each of these topics as they apply to a particular situation.

Slurry is a two-phase mixture of solid particles and a fluid. The two phases do not chemically react and can be separated by mechanical means. There are two types of slurry systems:

1. Non-settling slurries
2. Settling slurries

Non-settling slurries have the hydraulic flow characteristics of a viscous fluid. These type of slurry systems are designed according to standard procedures with allowances for the higher viscosity. The majority of slurry systems are the settling type. In settling systems the solids will tend to settle out of the carrier fluid. When the flow velocity is reduced in these systems, the fluid flow goes through settling phases. The tendency for settling is often countered by increasing the flow velocity.

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Flow Phases. The flow velocity of a slurry affects the mode of the flow. When the flow velocity is high and then is gradually slowed, the slurry passes through four flow modes:

- Homogeneous Flow: This term describes a system in which the solids are uniformly distributed throughout the liquid. This is the most desirable of all flow modes because the particles do not contact the wall as frequently, thus reducing abrasion
- Heterogeneous Flow: The solids tend to flow nearer the bottom of the pipe but do not actually slide on the pipe bottom. This is the most economical flow mode and is typically used for sand sized solids
- Saltation Flow: In this mode, solid particles tend to bounce along the bottom of the pipe. This flow is particularly aggressive in its abrasion of pipe.
- Sliding Bed Flow: This mode of flow is generally unsatisfactory. Solids slide and roll on the pipe bottom. Excessive corrosion in the pipe bottom occurs quickly. Blockages can occur frequently

Increasing the flow velocity will often avoid sliding bed and saltation flow. However, the operational cost, such as high power requirements, could increase significantly. The critical velocity of a slurry is the velocity range that the solid particles tend to drop out of suspension and settle to the bottom of the pipe. The critical velocity is determined by the particle size and shape, size distribution, concentration, particle density and carrier fluid density. Some particle solids form a viscous fluid with the liquid carrier. This is a homogeneous mode. For these materials when the flow velocity makes a transition from turbulent flow to laminar flow, the viscous, homogeneous fluid makes a transition from a smooth mixture to a separated mixture. When turbulence stops and laminar flow develops, the homogeneous mode of flow ends and the saltation or sliding bed mode begin. Turbulent flow is essential to keeping these type solids in suspension. When designing a piping system for this type of slurry consider:

- As the slurry viscosity increases, the flow velocity must be increased to prevent settling
- As the solids concentration increases, the flow velocity must be increased to prevent settling
- As the particle size decreases, the flow velocity must be increased to prevent settling

Slurries with high concentrations of fine size particles can be more abrasive than slurries with larger size particles. The basic reason is that the particle/wall contact is greater and more frequent with fine slurry.

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GAS FLOW

The flow capacity for thermoplastic piping transporting a gaseous product may be found through the use of the Mueller relationship for pressure drop in a plastic pipe as noted below.

$$Q = \frac{2826}{G^{0.425}} \sqrt[0.575]{\frac{P_1^2 - P_2^2}{L}}\, D^{2.725}$$

where Q = Gas flow rate in standard cubic feet per hour, SCFH
G = Specific gravity (Air = 1.0)
P_1 = Inlet pressure, psia
P_2 = Outlet pressure, psia
L = Pipeline length, feet
D = Inside diameter, inches

LIFE EXPECTANCY

Thermoplastic piping systems offer long, trouble free service. Piping manufacturers are continuously testing their products in accordance with ASTM procedures to ensure the long-term strength and performance of their products. Standard samples of pipe are held at constant pressure and temperature according to specifications. Manufacturers use high pressures and temperatures so that some samples are forced to fail. They then develop statistical predictions based on the test data as to the service life and long term strength of the pipe based upon the number of forced failures and the time it took them to fail. This data is plotted and a stress-life curve graph is developed. The stress-life curve provides a relationship between the expected life of the pipe and the internal stress at a given working pressure and temperature. A basis recommendation for all HDPE pipe systems is to expect a 50-year life from the system. The hydrostatic design stress according to the industry accepted formula as defined in ASTM D-2837.

$$P = \frac{2St}{(D - t)}$$

where S = Hydrostatic design stress
P = Working pressure
D = Average outside diameter
t = Minimum wall thickness

SYSTEM PRESSURE

Thermoplastic piping systems are designed for one of three types of service:

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1. Pressurized flow
2. Non-pressurized flow
3. Vacuum flow

When designing a pressurized pipe system, the pipe selected must hold the internal pressure safely and continuously. In a non-pressurized system such as a gravity flow sewer, pipe selection depends on other factors. Vacuum piping systems must use a pipe that resists collapse. The design engineer will use different design criteria and calculations for each type of installation.

POSITIVE PRESSURE PIPELINES

Many manufacturers of thermoplastic piping material use the standard dimension ratio (SDR) method of rating pressure pipe. SDR is the ratio of the pipe O.D. to the minimum thickness of the wall of the pipe. It can be expressed mathematically as:

$$\text{SDR} = \frac{D}{t}$$

where SDR = Standard Dimension Ratio
D = Pipe outside diameter in inches
t = Pipe minimum wall thickness in inches

For a given SDR the ratio of the O.D. to the minimum wall thickness remains constant. An SDR 11 means the O.D. of the pipe is eleven times the thickness of the wall. This remains true regardless of diameter. For example, a 14-inch O.D. pipe with a wall (t) of 1.273-inch is an SDR 11 pipe. An 8-inch O.D. pipe with a wall (t) of .785-inch is also an SDR 11 pipe. Common SDR ratios are SDR 9.3, SDR 11, SDR 13.5, SDR 15.5, SDR 17, SDR 19, SDR 21, SDR 26 and SDR 32.5. For high SDR ratios, the pipe wall is thin in comparison to the pipe O.D. For low SDR ratios, the wall is thick in comparison to the pipe O.D. Given two pipes of the same O.D., the pipe with the thicker wall will be stronger than the one with the thinner wall. Pipes with a high SDR rating have low-pressure ratings and pipe with low SDR ratings have high-pressure ratings because of the relative wall thickness.

The pressure rating of thermoplastic pipe is mathematically calculated from the SDR and the allowable hoop-stress. The allowable hoop-stress is commonly known as the long-term hydrostatic design stress. This is the stress level that can exist in the pipe wall continuously with a high degree of confidence that the pipe will operate under pressure for at least 50 years with safety. The American Society for Testing and Materials (ASTM) and the Plastics Pipe Institute (PPI) has adopted

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the following formula relating SDR and hydrostatic design stress as the standard for the industry.

$$P = \frac{2St}{(D - t)}$$

where P = Pressure rating (psi)
D = Pipe OD (inches)
t = minimum wall thickness (inches)
S = Hydrostatic Design Stress

$$\text{SDR} = \frac{D}{t}$$

From the formula you can see that all pipes of the same SDR (regardless of diameter) will have the same pressure rating for a given design stress.

Water Hammer/Pressure Surge. The effects and calculations for water hammer or pressure surge were covered in detail in chapter 3. The following section contains some key design considerations for handling the effects within thermoplastic piping systems.

Since all moving objects have mass and velocity, any flowing liquid has momentum and inertia. When flow is suddenly stopped, the mass inertia of the flowing stream is converted into a shock wave or high static head on the pressure side of the pipeline. Some of the more common causes of hydraulic transients are

1. The opening and closing (full or partial) of valves
2. Starting and stopping of pumps
3. Changes in turbine speed
4. Changes in reservoir elevation
5. Reservoir wave action
6. Liquid column separation
7. Entrapped air

Thermoplastic piping materials are well suited to handle occasional surge pressures. Some PE manufactures provide pipe that can withstand occasional surge pressures up to 2.5 times the rated pressure capability of the pipe without a cumulative effect. This is due to the long-term modulus of the material being only a fraction of the short-term modulus.

In general, good system design will eliminate quick opening/closing valves on anything but very short lines. The design engineer should use judgment with regard to the addition of surge pressures to operating pressures when selecting pipe SDRs. The following rules of thumb may be of help:

- Occasional shock pressures can be accommodated within the design safety factor. Due to the short time duration of the surge pressure, occasional shock

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wave surge pressures to 2.5 times the SDR pressure rating at 73.4°F are usually allowable

- If surge pressure or water hammer is expected in a system, keep the flow velocity on the low side of the velocity range

If surge pressure or water hammer is expected, maximize the time required to shut off a valve or reduce flow. A shutoff cycle 6–10 times the time period 2L/S is suggested to minimize surge pressures by gradually slowing the fluid flow. If constant and repetitive surge pressures are present, the excess pressure should be added to the nominal operating pressure when selecting the pipe SDR.

Cyclic Overpressure

There are many causes to short-term cyclic overpressure. Activities such as a stuck relief valve, a plugged discharge line or repetitive freeze/thaw cycles can cause extended rises in pressure. In steel, concrete, PVC or fiberglass pipe, the effect of the increased pressure can be devastating. With many of the thermoplastic piping materials the pipe wall is able to stretch (strain) with the freezing water and the pipe will return to its original condition after the frozen water has thawed. Although some residual strain may be evident, the physical properties of the pipe resin are not adversely affected and the performance of the pipe at normal operating conditions is not affected. Due to the innate elastic characteristics of many thermoplastic piping materials, they are capable of withstanding these types of cyclic loadings without damage to the pipe's performance. The effects of extended and repeated over pressure can be tolerated within specific limits. Many thermoplastic pipes have an inherent ability to recover from the strain of overpressures. If the recovery period at a normal level of stress is equal to or greater than the duration of the over pressure, the pipe can be subjected to the stresses for short periods without affecting their long term strength, endurance, and performance.

The basic limitation on short-term overpressure cycles is to stay within the elastic limits of the pipe material. If the system pressure exceeds 2.5 times the rated pressure of the pipe for any length of time, permanent strain or deformation of the pipe occurs. As a result, the expected service life of the pipe can be dramatically reduced. When overpressure cycling is expected as a regular condition of operation, the highest pressure anticipated the majority of the operating times should be considered as the operating pressure and it should be treated as though it would persist continuously for the design life of the system.

Longitudinal Stress from Internal Pressure

When a fully restrained pipeline such as a buried or anchored pipeline is pressurized, longitudinal stresses develop in the pipe wall. The longitudinal stress is calculated as follows:

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$$S_L = \frac{\mu P(D - t)}{2t}$$

where S_L = Longitudinal tensile stress, psi
μ = Poisson's ratio
P = Internal operating pressure, psi
D = Pipe outside diameter, inches
t = Pipe wall thickness, inches

Thermal Expansion and Contraction

Thermal expansion and contraction are key items of concern in the design of a thermoplastic piping system. Design parameters should be developed and incorporated into the installation specifications. Thermoplastic piping materials have a higher coefficient of expansion than some other common pipeline materials, however, the forces generated by thermal stresses are much lower because the modulus of elasticity is lower and it is capable of stress relaxation.

There are many methods available to the designer to control expansion or contraction. One method is to install the pipeline when it is within 10 to 15 degrees Farenheit of its operating temperature. Other methods of controlling expansion/contraction are pertinent to certain types of installations and are briefly discussed.

Supported Pipelines

A common practice is to install the pipe in a warm condition in a straight line while it is in an expanded state. As the pipeline cools it develops a tensile stress and the pipeline remains straight between supports. As the pipe warms to its installation temperature due to seasonal change or operating conditions, it returns to its installation condition and straightness. In this manner, sag between supports is minimized.

Overland Pipes

Controlling the expansion and contraction of overland surface lines is difficult because the uneven soil friction between the pipe and the ground does not allow distributed lateral deflections to occur uniformly. In the worse case, all deflection may occur in one area where friction is low and the pipe may kink. This condition will most likely occur in empty lines or where large, sudden operating temperature changes occur. If overland pipelines are installed in a snaked pattern, thermal expansion/contraction can be controlled through control of lateral deflection. During pipeline warming, the "S" configuration becomes slightly greater. As the pipe cools, the pipeline becomes straighter. Surface lines that are continuously operated full of fluid normally experience small, slow temperature variations and are easy to control. The weight of the fluid also increases friction and reduces deflection. How-

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ever, it may necessary to anchor the line at intervals to direct and limit the deflection in any one segment of the pipeline.

Buried Pipelines

Buried pipeline installations offer a significant degree of restraint due to soil friction. This is further controlled because the pipe usually lies in a slight "S" curve in the trench as it is installed. Because the temperature of the soil is fairly constant, temperature changes that do occur take place over a yearly season. Due to the enormous heat sink capability of the earth, the magnitude of any temperature change is reduced and the time required to effect that temperature change extended.

A buried process pipeline operating at a specific temperature may develop some initial thermal stress upon start-up. This is usually restrained by soil friction and dissipated with time by stress relaxation. As the pipeline continues operation, it tends to bring the soil envelope surrounding the pipeline into equilibrium with the operating temperature. If a minor temperature change does occur, its effect is further minimized by the massive thermal inertia within the pipe wall and in the soil surrounding the pipeline.

TRANSITION CONNECTIONS

The stress and the corresponding force developed by temperature change in a restrained pipeline are independent of the length and the burial conditions of the pipe. If pipe movement at the end sections cannot be tolerated, the pipe must be anchored mechanically to resist the thermal forces. A normal design practice is to use concrete collars to transfer the thermal force into the soil enveloping the pipe. Adequate frictional resistance must also be provided to transfer the force from the pipe into the concrete collar. If the pipe is not anchored at the ends to resist movement, portions may expand or contract as the temperature changes. This change in length will extend into the burial trench to a point at which the frictional resistance of the backfill is equal to the thermal force. The normal design practice for considering the movements or forces are to; isolate the end connection, by means of an anchor or collar, from the effects of thermal movement of the rest of the pipeline. The following example may be helpful.

EXAMPLE

Assume a 4 ινψη diameter SDR 15.5 process pipeline is buried five feet deep in dense sandy soil with a high water table. The ground temperature is 60°F. Under intermittent operating conditions, it must carry 40°F water 1000 ft. to a remote part of the plant in a straight path. Calculate the following:

- The temperature change
- The theoretical strain

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- The theoretical length change
- The instantaneous tensile stress in the pipe wall
- The tensile force
- Design a collar to isolate the terminal connection from the effects of thermal contraction

Pipe:		4-inch SDR 15.5
Pipe Wall Cross-sectional Area		3.83 square inches
Linear Coefficient of Thermal Expansion		1.2×10^{-4} in./in./μF
Instantaneous Modulus of Elasticity	E	180,000 psi at 73.4 μF
Temperature Change	μT	20 μF
Soil Coefficient of Friction	μ	0.10
Length of Run		L 1000 feet
Soil Density	μ	130 pounds per cubic foot
Depth of Burial	h	5 feet

Calculate:

Thermal Strain:

$\epsilon = \alpha \Delta T$

$\mu = \mu 1.2 \times 10^{-4}$ in./in./ (F)(20 (F) = .0024 inch per inch

Theoretical-Instantaneous Unrestrained Contraction:

$\Delta L = L\epsilon$

$$\Delta L = 1000 \text{ ft} \left(\frac{12 \text{ inch}}{\text{ft}} \right) \left(\frac{.0024 \text{ inch}}{\text{inch}} \right) = 28.8 \text{ inches}$$

Note: Since the soil restrains the pipe, it will not change length but will instead develop tensile stress due to contraction.

Theoretical Tensile Stress: $E = \dfrac{\sigma}{\epsilon}$

$\sigma = E\epsilon = (180{,}000 \text{ psi})(.0024) = 432 \text{ psi}$

Actual Tensile Stress: (per ASTM D2513)

$$\sigma = \frac{432}{2} = 216 \text{ psi}$$

Tensile stress

Actual Tensile Force: $F = \sigma \xi A$

$F = (216 \text{ psi})(3.83 \text{ sq. in.}) = 827.3 \text{ lbs. (tensile)}$

Soil Frictional Resistance: $f = \mu N$

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where Soil Pressure $= h = \dfrac{(130 \text{ lbs})(5 \text{ ft})}{\text{cubic ft}} = 650 \text{ psf} = 4.5 \text{ psi}$

Normal Pressure $= N =$ Normal force due to soil pressure on circumference of pipe ring one inch wide

$N = ((D) \times (1'' \text{ ring}) \times (\text{soil pressure})$
$= ((4.5'') \times (1'') \times (4.5 \text{ psi})$
$= (14.14 \text{ sq. in.})(4.5 \text{ psi}) = 63.63 \text{ lbs. per in. of pipe}$

Frictional Resistance $f = (N = (0.10)(63.63 \text{ lbs./in.})$
$= 6.363$ lb. per inch of pipe due to soil friction

Note: Beyond 122.8 inches (10.2 ft.) the soil friction will overcome the tensile stress force developed by thermal contraction of the pipeline. This is calculated by dividing the tensile force in the pipe by the frictional resistance of the soil (i.e.: 827.3 lbs. (6.363 lbs./in. = 130 inches).

Theoretical Movement of Unrestrained Ends:

$\Delta L = (130 \text{ inch}).0024 \text{ in/in} = .312 \text{ inches}$

DESIGN OF COLLAR

By pouring a square concrete collar around the pipe and branch saddles into undisturbed soil, the tensile force of 827.3 lbs. is removed from the pipe connection and is evenly distributed into the soil. Assume a collar 12 inches square and 6 inches wide is used.

Area of Collar $= A = (12'' \times 12'') - (\text{Cross Sectional Area of Pipe})$
$= (144 - 16)$ sq. in. $= 128$ sq. in. surface area

Compressive Stress on soil due to load transfer by collar face:

$S = F \,(\, A = 827.3 \text{ lbs.} \,(\, 128 \text{ sq. in.} = 6.5 \text{ psi}$

DESIGN CONSIDERATIONS FOR VARIOUS THERMOPLASTIC PIPE MATERIALS

Polyvinyl Chloride (PVC)

Polyvinyl chloride (PVC) is the most widely used thermoplastic piping system. PVC is stronger and more rigid than the other thermoplastic materials. When specifying PVC thermoplastic piping systems particular attention must be paid to the high coefficient of expansion-contraction for these materials in addition to effects of temperature extremes on pressure rating, viscoelasticity, tensile creep, ductility, and brittleness.

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PVC pipe is available in sizes ranging from ¼ to 16 inch, in Schedules 40 and 80. PVC piping shall conform to ASTM D 2464 for Schedule 80 threaded type; ASTM D 2466 for Schedule 40 socket type; or ASTM D 2467 for schedule 80 socket type.

Maximum allowable pressure ratings decrease with increasing diameter size. To maintain pressure ratings at standard temperatures, PVC is also available in Standard Dimension Ratio (SDR). SDR changes the dimensions of the piping in order to maintain the maximum allowable pressure rating.

For piping larger than 4 inches diameter, threaded fittings should not be used. Instead socket welded or flanged fittings should be specified. If a threaded PVC piping system is used, two choices are available, either use all Schedule 80 piping and fittings, or use Schedule 40 pipe and Schedule 80 threaded fittings. Schedule 40 pipes will not be threaded. Schedule 80 pipes would be specified typically for larger diameter pipes, elevated temperatures, or longer support span spacing. The system is selected based upon the application and design calculations.

The ranking of PVC piping systems from highest to lowest maximum operating pressure is as follows: Schedule 80 pipe socket-welded; Schedule 40 pipe with Schedule 80 fittings, socket-welded; and Schedule 80 pipe threaded. Schedule 40 pipe provides equal pressure rating to threaded Schedule 80, making Schedule 80 threaded uneconomical. In addition, the maximum allowable working pressure of PVC valves is lower than a Schedule 80 threaded piping system.

Acrylonitrile-Butadiene-Styrene (ABS)

Acrylonitrile-Butadiene-Styrene (ABS) is a thermoplastic material made with virgin ABS compounds. Pipe is available in both solid wall and cellular core wall, which can be used interchangeably. Pipe and fittings are available in 1½ inch through 12 inch. The pipe can be installed above or below grade.

ASTM D 2282 specifies requirements for solid wall ABS pipe. ASTM D 2661 specifies requirements for solid wall pipe for drain, waste, and vent pipe and fittings with a cellular core. Solid wall ABS fittings conform to ASTM D 2661. ASTM D 3311 specifies the drainage pattern for fittings.

ABS compounds have many different formulations that vary by manufacturer. The properties of the different formulations also vary extensively. ABS shall be specified very carefully and thoroughly because the acceptable use of one compound does not mean that all ABS piping systems are acceptable. Similarly, ABS compositions that are designed for air or gas handling may not be acceptable for liquids handling.

Pigments are added to the ABS to make pipe and fittings resistant to ultraviolet (UV) radiation degradation. Pipe and fittings specified for buried installations may be exposed to sunlight during construction, however, and prolonged exposure is not advised.

ABS pipe and fittings are combustible materials, however they may be installed in noncombustible buildings. Most building codes have determined that ABS must

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be protected at penetrations of walls, floors, ceilings, and fire resistance rated assemblies. The method of protecting the pipe penetration is using a through-penetration protection assembly that has been tested and rated in accordance with ASTM E 814. The important rating is the "F" rating for the through penetration protection assembly. The "F" rating must be a minimum of the hourly rating of the fire resistance rated assembly that the ABS plastic pipe penetrates. Local code interpretations related to through penetrations are verified with the jurisdiction having authority.

Chlorinated Polyvinyl Chloride (CPVC)

Chlorinated polyvinyl chloride (CPVC) is more highly chlorinated than PVC. CPVC is commonly used for chemical or corrosive services and hot water above 140°F and up to 210°F. CPVC is commercially available in sizes of ¼ inch to 12 inch for Schedule 40 and Schedule 80. Exposed CPVC piping should not be pneumatically tested, at any pressure, due to the possibility of personal injury from fragments in the event of pipe failure.

ASTM specifications for CPVC include: ASTM F 437 for Schedule 80 threaded type; ASTM F 439 for Schedule 80 socket type; and ASTM F 438 for Schedule 40 socket type. However, Schedule 40 socket may be difficult to procure.

Polyethylene (PE)

Polyethylene (PE) piping material properties vary as a result of manufacturing processes. Figure 4.14 lists the common types of PE, although an ultra high molecular weight type also exists. PE should be protected from ultraviolet radiation by the addition of carbon black as a stabilizer; other types of stabilizers do not protect adequately. PE piping systems are available in sizes ranging from ½ inch to 30 inch. Like PVC, PE piping is available in SDR dimensions to maintain maximum allowable pressure ratings.

Type	Standard	Specific Gravity
Low Density (LDPE)	ASTM D 3350, Type I	0.91 TO 0.925
Medium Density (MDPE)	ASTM D 3350 Type II	0.926 to 0.940
High Density (HDPE)	ASTM D 3350 Type III and ASTM D 1248 Type IV	0.941 to 0.959

FIGURE 4.14 Polyethelene designations.

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CHAPTER 5
ABOVE GROUND PIPE DESIGN

The installation of plastic pipe above ground is similar to the installation of other types of pipe. There are, however, differences, and these differences must be taken into account when planning and installing a system of plastic pipe to deliver material from one point to another. Not all designers and installers have an extensive understanding of the requirements for working with plastic pipe. In the scheme of things, plastic pipe is fairly new to the piping industry. Yes, the pipe has been available for many years, but it's use was slow to catch on in some regions.

When we talk of plastic pipe it might seem as though we are referring to one type of pipe. In one sense, we are, but there are many types of plastic pipe, and the various types of materials can require different installation guidelines. Whenever you are working with plastic pipe it is wise to obtain specifications and instructions directly from the manufacturer of the product. There is no substitute for the authority of recommendations provided by a product manufacturer.

There are critics of plastic pipe. Some people feel that the material is not up to the rigors which can be withstood by other types of materials.

In fact, manufacturers have insisted on exacting quality-control procedures to produce products that are dependable for their intended uses. Table 5.1 shows the application ranges of plastic pipe. In addition to the manufacturers, many testing agencies have been involved in the evolution of plastic piping. For example, when problems were experienced with polybutylene (PB) piping having faulty joints and unexpected ruptures, the development of cross-linked polyethylene (PEX) came to the industry. Professional associations, contractors, testing agencies, manufacturers, and consumers all have an eye on the use of plastic pipe.

As good as plastic pipe is, it is only as good as its installation will allow for. If the product is not installed properly, problems are likely to occur. This means that individuals responsible for the installation of plastic pipe must be trained to work

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with the type of material they are installing. Designers must take into account individual characteristics for various types of plastic pipe when they create working drawings and specifications. Application ranges of plastic pipe are shown in Table 5.1.

If you or your crews are not familiar with plastic piping, you should seek competent training and instruction. Sources for such services and information can include manufacturers, distributors, experienced contractors, books, and training seminars. You should learn all you can about the materials you will be installing before attempting an installation. Cutting corners can come back to haunt you quickly in the form of costly repairs, a damaged reputation, insurance claims for losses or damage, or worse.

Many contractors have learned that a little in-house training can go a long way in reducing on-the-job problems. While the training of crews is an overhead expense, it can be some of the best money a company will spend. Sending crews to a training seminar is good business, but how much will they learn from a few handouts and the spoken word of experts? Potentially, they will learn a great deal, but there is no substitute for hands-on training. Investing the time and money to train crews before putting them in the field may be one of the best investments a contractor can make.

TABLE 5.1 Application Range of Plastic Pipe

Application Range of Plastic Pipe

	Transported Medium	Recommended Material	Conditionally Suitable
Laid above ground	Solvents	PVDF	PP, PE
	Acids	PVDF, PVC	PP, PE
	High Purity Acids	PVDF	
	Alkalis	PVC, PP, PE	
	Hot Medium	PVDF, PP	
	Swimming Pool Water	PVC	PE
	Rain Water	PVC	
	Waste Water	PP, PE	
	High Purity Water	PVDF	PP, PVC
	Potable Water	PVC, PE	
Buried in ground	Potable Water	PVC, PE	
	Waste Water	PVC, PE	
	Gas	PVC, PE	
	Drainage	PVC	
	Cable Protection	PVC, PE	

(Courtesy George Fischer Engineering Handbook)

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A number of professions require continuing education in order to remain licensed for the profession. This is true of the trades in some states, but many states don't require ongoing education for licensed trades. In any case, it is the responsibility of the contractor to guarantee that crews sent to do a job are competent for the task at hand. If something goes wrong in the field, who is going to be blamed? The individuals performing the work will be the first target, but the company they work for will also feel the heat. The odds of having your crews and company dragged into controversy and potential lawsuits can be turned in your favor with adequate training programs.

When I speak of adequate training programs, I am not suggesting that you put your people through a rigorous ordeal that lasts for months. Depending upon the type of work you are doing, a single day may be adequate for the training process. A few days of training will almost always be adequate for experienced tradespeople who simply need to be brought up to speed with a particular type of material. Don't overlook the training opportunity. More and more contractors are seeing the value of in-house training, and you should give it serious consideration.

RECEIVING MATERIALS

Receiving materials on a job site is such a common practice that workers often take it for granted. This can be a mistake. How the materials are handled can affect the entire installation. A successful installation starts with design and ends with testing and putting the system into operation. This process includes the unloading of materials.

When materials are not handled properly, they can be damaged. The damage may go unnoticed until a system is installed and tested. This has happened more than once. For example, there was a crew installing a PVC pipeline in cold weather. The installation went well, until the test was performed on the system. It was then that long cracks in the PVC pipe were discovered.

After investigating the incident, It was discovered that some of the pipe had been handled roughly during the installation. Workers had been dropping the pipe, instead of laying it down. The rocky ground provided a hard surface for the pipe to land on. Cold PVC and hard rocks are not a good combination. The cracks were thin enough to avoid visual detection, but they leaked when the test was applied. This meant cutting out sections of the pipeline and replacing the damaged sections. Not only was this time consuming and expensive, it was embarrassing. If the workers had handled the pipe properly, the entire problem would have been avoided.

Instructing your workers in proper pipe handling is essential to your success. Know and understand the materials you are working with. Handle them accordingy. Once the materials are on the job site, you will need to provide proper storage conditions. Thermal expansion and contraction of plastic pipe is illustrated in

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Figure 5.1. Solvent welded pressure ratings vs. service temperature for CPVC and PVC pipe is shown in Figure 5.2.

Storing plastic pipe does not require sophisticated facilities. Plastic offers excellent resistance to weathering and can usually be stored outside. How the pipe is stored depends on the type of plastic you are working with and the conditions that the pipe will be exposed to. For example, you could place PVC pipe on a rack and leave it exposed to a hot sun for several days without any damage. But, don't try this with ABS pipe, unless the pipe is fully supported. By nature, ABS pipe sags when laid in direct, hot sunlight. On the other hand, ABS can take cold weather very well without becoming brittle. PVC pipe cannot. You must know the characteristics and needs of the specific materials you are working with.

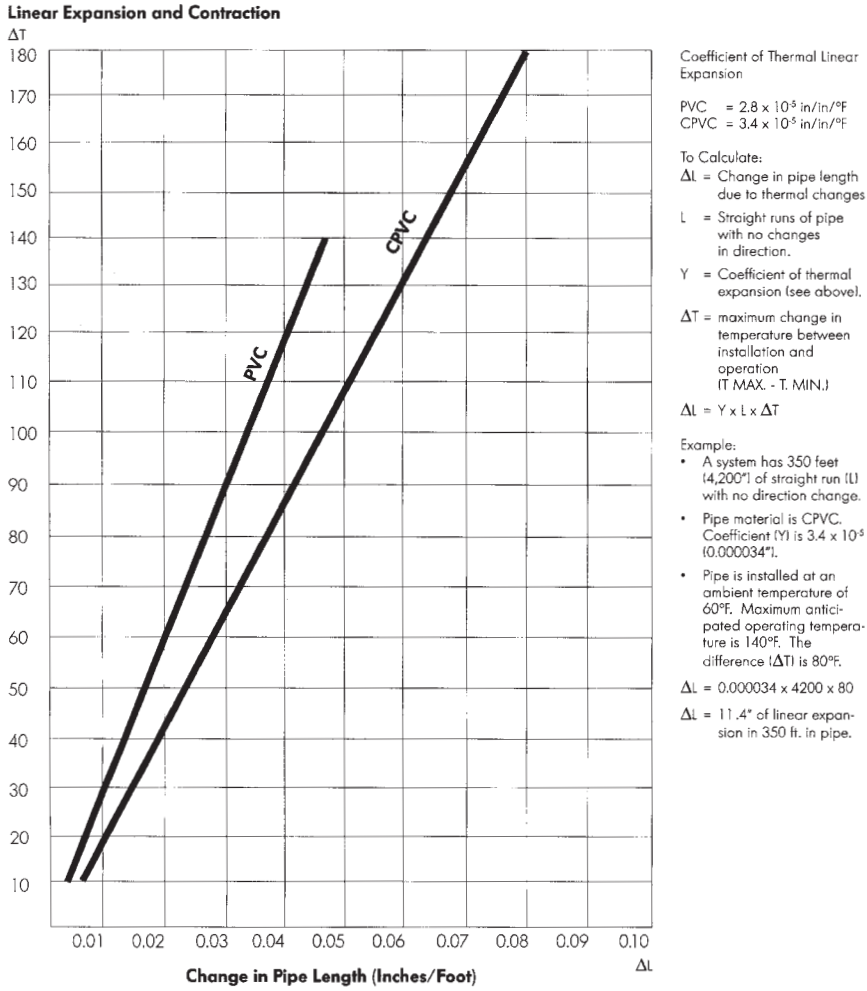

FIGURE 5.1 Thermal expansion and contraction. *(Courtesy George Fischer Engineering Handbook)*

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Solvent-Welded Pressure Rating vs. Service Temperature — CPVC and PVC

				P														
				73°F		90°F	100°F	110°F	120°F		130°F		140°F		160°F	180°F	200°F	210°F
Nom. Size	D Outside Dia.	t Wall	DR=	PVC f=1 S=2000	CPVC f=1 S=2000	PVC f=0.75 S=1500	PVC f=0.62 S=1240	PVC f=0.50 S=1000	PVC f=0.40 S=800	CPVC f=0.65 S=1300	PVC f=0.30 S=600	CPVC f=0.57 S=1135	PVC f=0.22 S=440	CPVC f=0.50 S=1000	CPVC f=0.40 S=800	CPVC f=0.25 S=500	CPVC f=0.20 S=400	CPVC f=0.16 S=320
1/2	.840	.147	5.714	848	848	636	526	424	339	552	255	484	187	424	339	212	170	136
3/4	1.050	.154	6.818	688	688	516	426	344	275	447	206	392	151	344	275	172	138	110
1	1.315	.179	7.346	630	630	473	390	315	252	410	189	359	139	315	252	158	126	101
1 1/4	1.660	.191	8.691	520	520	390	322	260	208	338	156	296	114	260	208	130	104	83
1 1/2	1.900	.200	9.500	471	471	353	292	235	188	306	141	268	104	235	188	118	94	75
2	2.375	.218	10.894	404	404	303	251	202	162	263	121	230	89	202	162	101	81	65
2 1/2	2.875	.276	10.417	425	425	319	263	212	170	276	127	242	93	212	170	106	85	68
3	3.500	.300	11.667	375	375	281	233	188	150	244	113	214	83	188	150	94	75	60
4	4.500	.337	13.353	324	324	243	201	162	130	210	97	185	71	162	130	81	65	52
6	6.625	.432	15.336	279	279	209	173	140	112	181	84	159	61	140	112	70	56	45
8	8.625	.500	17.250	246	246	185	153	123	98	160	74	140	54	123	98	62	49	39

P = Pressure rating of pipe at service temperatures (psi)
S = Hydrostatic design stress (psi)
D = Outside diameter of pipe (inches)

1) Figures for pressure rating at 73°F are rounded off from actual calculated values. Pressure ratings for other temperatures are calculated from 73°F values.
2) Pressure rating values are for PVC (12454-B) and CPVC (23447-B) pipe and for most sizes are calculated from the experimentally determined long-term strength of PVC1 and CPVC extrusion compounds. Because molding compounds may differ in long-term strength and elevated temperature properties from pipe compounds, piping systems consisting of extruded pipe and molded fittings may have lower pressure ratings than those shown here, particularly at the higher temperatures. Caution should be exercised when designing PVC systems operating above 100°F and CPVC systems operating above 180°F.
3) The pressure ratings given are for solvent-cemented systems. When adding valves, flanges or other components, the system must be derated to the rating of the lowest component. (Pressure ratings: molded or cut threads are rated at 50% of solvent-cemented systems; flanges and unions are 150 psi; for valves, see manufacturer's recommendation.)

FIGURE 5.2 Solvent-welded pressure rating vs service temperature for CPVC and PVC pipe. *(Courtesy George Fischer Engineering Handbook)*

When plastic pipe and fittings are to be stored for an extended time, they should be kept under a light tarp or in a ventilated, covered area. How often have you seen these materials stored in the large trailers retired from use with 18-wheelers? These storage trailers keep the materials dry, but excessive heat can build up in the container, and heat can be a problem for some plastics. This is why a well-ventilated, covered area is more desirable for storage.

Sunlight can degrade plastics with the ultraviolet rays associated with the rays of the sun. Plastic products should be kept clean, dry, free of ice, and ready for instant installation. The sun is not the only enemy of plastic pipe. You must protect the pipe from extraordinary deflection. If pipe is stacked too high on itself, the pipe diameter can be affected to an unacceptable level. A rule-of-thumb for stacking plastic pipe is to avoid pipe stacks that are more than 3 feet in height. It is common to double-stack bundled pipe.

Belled pipe should be stored so that alternate rows of bells are inverted. This minimizes the loading on the bell. This procedure is especially important if belled pipe is to be stored for an extended time. As with any pipe rack for plastic pipe, racks for belled pipe should be smooth and free of any burrs or sharp edges that might compromise the integrity of the plastic pipe.

GENERAL ABOVE-GROUND RECOMMENDATIONS

There are general above-ground recommendations for the installation of plastic pipe. But, never make assumptions based on average installations.

Confirm manufacturer's recommendations for all of your installation projects. The anchoring, support spacing, and hanger designs used with plastic pipe can differ from the procedures used with other types of pipe. Another special consideration with plastic pipe is the potential risk of damage from different types of impact. Let's go over some of these basics.

Support Spacing

The rules for support spacing when working with plastic pipe are different than those used for metal pipe. Both the tensile and compression strengths of plastic pipe are lower than those of metal pipe. Recommended spacing is illustrated in Table 5.2.

This means that additional support is needed for plastic pipe. Additionally, the tensile strength of thermoplastic pipe decreases when the pipe gets hot. Therefore, more support is needed. Conditions can exist when temperature ratings are so high that thermoplastic pipe will require continuous support.

Thermoset requirements for support are not as extensive as those used with thermoplastic pipe. In fact, thermoset installations are much more in line with the requirements set forth for metal pipes. Check your local code requirements for specific spacing data on supports.

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ABOVE GROUND PIPE DESIGN

TABLE 5.2 Recommended Support Spacing (in feet)

Recommended Support Spacing* (In Feet)

Nom. Pipe Size (In.)	PVC Pipe Schedule 40 Temp. °F					PVC Pipe Schedule 80 Temp °F				CPVC Pipe Schedule 80 Temp. °F						
	60	80	100	120	140	60	80	100	120	140	60	80	100	120	140	180
1/2	4 1/2	4 1/2	4	2 1/2	2 1/2	5	4 1/2	4 1/2	3	2 1/2	5 1/2	5 1/2	5	4 1/2	4 1/2	2 1/2
3/4	5	4 1/2	4	2 1/2	2 1/2	5 1/2	5	4 1/2	3	2 1/2	5 1/2	5 1/2	5 1/2	5	4 1/2	2 1/2
1	5 1/2	5	4 1/2	3	2 1/2	6	5 1/2	5	3 1/2	3	6	6	6	5 1/2	5	3
1 1/4	5 1/2	5 1/2	5	3	3	6	6	5 1/2	3 1/2	3	6 1/2	6 1/2	6	6	5 1/2	3
1 1/2	6	5 1/2	5	3 1/2	3	6 1/2	6	5 1/2	3 1/2	3 1/2	7	7	6 1/2	6	5 1/2	3 1/2
2	6	5 1/2	5	3 1/2	7	7	6 1/2	6	4	3 1/2	7	7	7	6 1/2	6	3 1/2
2 1/2	7	6 1/2	6	4	3 1/2	7 1/2	7 1/2	6 1/2	4 1/2	4	8	7 1/2	7 1/2	7 1/2	6 1/2	4
3	7	7	6	4	3 1/2	8	7 1/2	7	4 1/2	4	8	8	8	7 1/2	7	4
4	7 1/2	7	6 1/2	4 1/2	4	9	8 1/2	7 1/2	5	4 1/2	9	9	9	8 1/2	7 1/2	4 1/2
6	8 1/2	8	7 1/2	5	4 1/2	10	9 1/2	9	6	5	10	10 1/2	9 1/2	9	8	5
8	9	8 1/2	8	5	4 1/2	11	10 1/2	9 1/2	6 1/2	5 1/2	11	11	10 1/2	10	9	5 1/2
10	10	9	8 1/2	5 1/2	5	12	11	10	7	6	11 1/2	11 1/2	11	10 1/2	9 1/2	6
12	11 1/2	10 1/2	9 1/2	6 1/2	5 1/2	12	11	10	7	6	12 1/2	12 1/2	12 1/2	11	10 1/2	6 1/2
14	12	11	10	7	6	13 1/2	13	11	8	7						
16	12 1/2	11 1/2	10 1/2	7 1/2	6 1/2	14	13 1/2	11 1/2	8 1/2	7 1/2						

Note: This data is based on information supplied by the raw material manufacturers. It should be used as a general recommendation only and not as a guarantee of performance or longevity.

*Chart based on spacing for continuous spans and for uninsulated lines conveying fluids of specific gravity up to 1.00.

(Courtesy George Fischer Engineering Handbook)

Hangers

The types of hangers used with plastic pipe can be critical to the success of the pipe's function. Using the wrong type of hanger can cause stress on a pipe that will shorten the useful life of the conduit. Overall, most designers choose hangers that have a large bearing area to disperse the load of the pipe over the largest area feasible. A variety of hangers are illustrated in Figures 5.3, 5.4, 5.5, 5.6, and 5.7.

Hangers that are manufactured for metal pipe can often be modified and used with plastic pipe. Horizontal pipe is often hung with either a sling clamp or a clevis hanger.

Shoe supports can be used when conditions are favorable for them. Remember to choose hangers that offer the largest area of support that is practical.

It is not unusual to find a sleeve of sheet metal installed between the pipe and its hanger. Why is this done? The sheet metal spreads the load over a larger area of the pipe to reduce stress on the pipe.

When U-bolt hangers and roller hangers are used, the plastic pipe should be fitted with a protective sleeve. Medium-gage sheet metal is often used to fabricate these sleeves. Another type of sleeve is a section of plastic pipe that has been cut in half to fit over the pipe being secured. A rule-of-thumb for plastic pipe installations where excessive temperature calls for continuous support is to use a smooth structural angle or channel.

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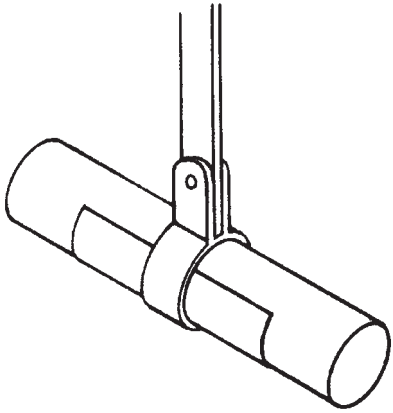

FIGURE 5.3 Band hanger with protective sleeve. *(Courtesy George Fischer Engineering Handbook)*

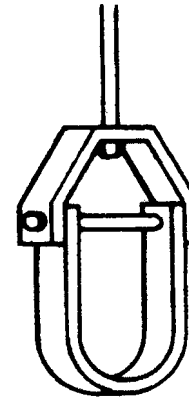

FIGURE 5.4 Clevis hanger. *(Courtesy George Fischer Engineering Handbook)*

Roller hangers are recommended when a pipe might move axially.

Thermal expansion is possible due to fluid or environmental temperature variations. This may cause movement that is best handled by roller hangers. In such cases, the pipe should be fitted with a protective sleeve.

Plastic pipe that rubs against a steel support can be damaged to a point that the useful life of the pipe is reduced. Any abrasive surface can be destructive to plastic pipe. Wood is sometimes used to protect plastic pipe from abrasive surfaces, but wood can deteriorate. A thermoplastic pad, such as PVC or polyethylene

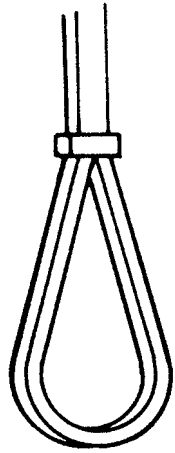

FIGURE 5.5 Adjustable solid ring swivel type. *(Courtesy George Fischer Engineering Handbook)*

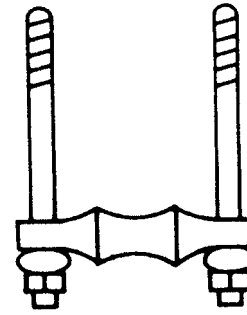

FIGURE 5.6 Single pipe roll. *(Courtesy George Fischer Engineering Handbook)*

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ABOVE GROUND PIPE DESIGN

makes a better protective surface. Pipe roll plates as illustrated in Figure 5.8 are also effective supports.

Your local code will dictate where hangers must be installed, but remember to install them as close as possible to all 90-degree bends.

Vertical installations must be supported in compliance with code regulations. The support intervals are not as frequent as those used for horizontal piping, but they are just as necessary. The base of all stacks must be supported. From there, the vertical intervals vary, so check your local code requirements.

It is preferable to avoid heavy weight loads on the base of vertical runs. The weight load can be controlled with riser clamp or double-bolt pipe clamps, illustrated in Figures 5.9 and 5.10.

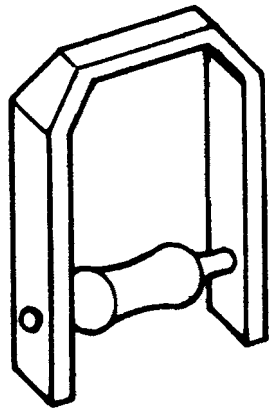

FIGURE 5.7 Roller hanger. *(Courtesy George Fischer Engineering Handbook)*

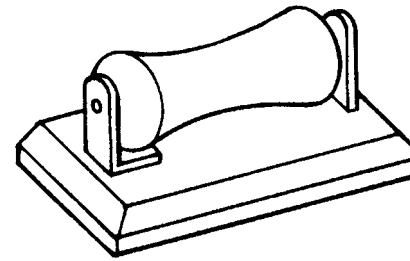

FIGURE 5.8 Pipe roll and plate. *(Courtesy George Fischer Engineering Handbook)*

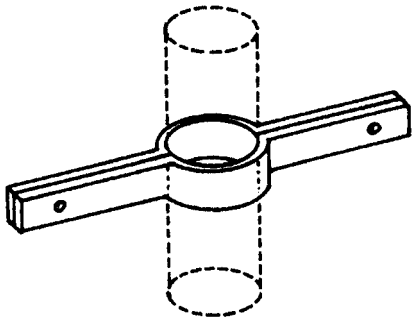

FIGURE 5.9 Riser clamp. *(Courtesy George Fischer Engineering Handbook)*

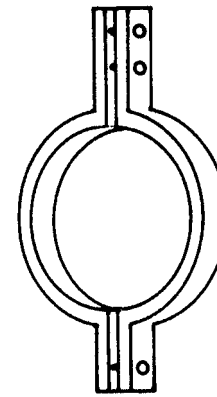

FIGURE 5.10 Double-bolt clamp. *(Courtesy George Fischer Engineering Handbook)*

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When using these devices, you must avoid tightening the supports to a point where they will compress the wall of the pipe being secured. It's common to install these supports directly beneath couplings. In this way, the shoulder of the coupling rests on the support for maximum results. A trick of the trade when you need a support in a location where there is no fitting is to cut the hub of a fitting from the fitting and bond it to the vertical pipe. The shoulder of the hub can then rest on your support. Placing your supports under the shoulders of fittings makes it easier to maintain support without compressing the pipe too much. Continuous support arrangements are illustrated in Figure 5.11.

Valves are a common part of a piping installation. When the valves are larger than 2 inches in diameter, they should be supported. Unsupported valves can put stress on the joints between the valve and the pipe ends. In horizontal installations, it's a good idea to support the pipe on both sides of a valve, near the point of connection. Support arrangements are illustrated in Figure 5.12

Pipe movement must be controlled. This is most often done with the use of anchors and guides. These devices can direct the motion of a pipe within a defined range. Once an anchor is installed, there is no axial or transverse movement of the pipe. When axial movement is allowable, but transverse movement is not, guides are installed. Achorage methods are illustrated in Figures 5.13 and 5.14.

The use of anchors and guides should be designed in a way to function without point loading the pipe. You can expect to find anchors and guides whenever expansion joints are used. Long runs or piping are logical places to install anchors and guides. Directional changes in piping also call for anchors. When 90-degree bends are installed, anchors should be installed as close to the offsets as possible. These are illustrated in Figure 15.5.

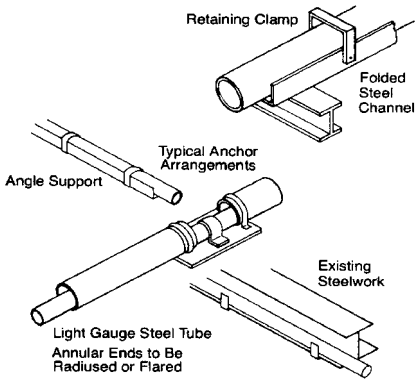

FIGURE 5.11 Continuous support arrangements. *(Courtesy George Fischer Engineering Handbook)*

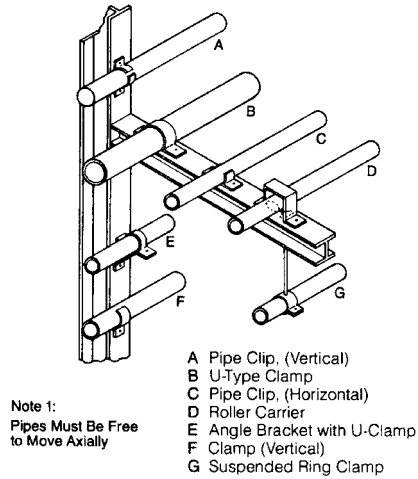

FIGURE 5.12 Typical support arrangements. *(Courtesy George Fischer Engineering Handbook)*

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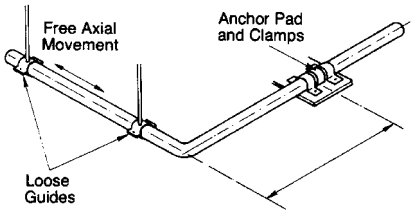

FIGURE 5.13 Continuous support arrangements. *(Courtesy George Fischer Engineering Handbook)*

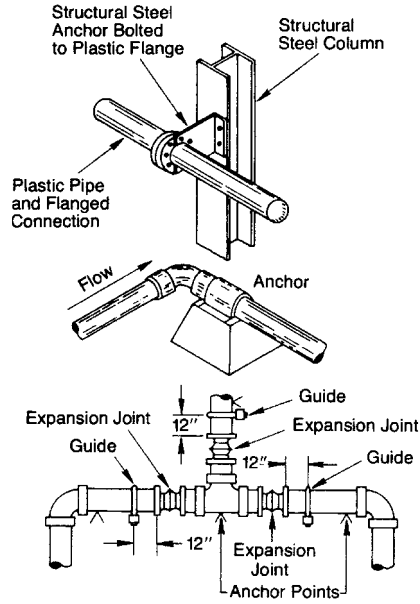

FIGURE 5.14 Anchoring methods. *(Courtesy George Fischer Engineering Handbook)*

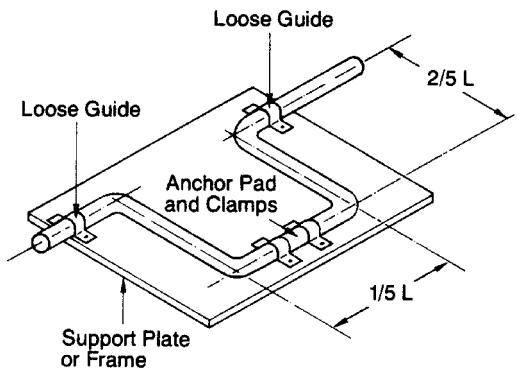

FIGURE 5.15 Anchoring changes in direction. *(Courtesy George Fischer Engineering Handbook)*

POLYETHYLENE PIPE

Polyethylene pipe (PE) is just one type of pipe that you may consider using in above-ground applications. The toughness, flexibility, light weight, and joint integrity of polyethylene pipe make it an excellent choice for above-ground installations. What

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can PE pipe be used for? It has seen use for a number of applications. Gas and oil transportation are among its uses. PE pipe has been used for temporary water lines, many types of bypass lines, dredge lines, fines disposal, and mine tailings, among other things. Slurry transport in many industries is another point of use for PE pipe. Not only is PE pipe versatile, it is economical.

Design criteria which may influence the use of PE pipe can include, temperature, ultraviolet radiation, any potential impact or loading, and chemical exposure. Most resources agree that PE pipe can be used in temperature extremes ranging from a low of –75F to a high of 150F. This is quite a range. However, the wide range of temperatures can call for specific engineering design to accommodate the extreme temperatures. Individual pipe manufacturers can provide detailed instructions on what to look out for when using PE pipe in extreme temperatures.

The pressure capability of PE pipe is established by the Hydrostatic Stress Board of the Plastics Pipe Institute. A hydrostatic design stress (HDS) is recommended by the board. Pressure capability is based on the long-term hydrostatic strength (LTHS) of the polymer used in the manufacturing of the pipe. The strength of a pipe is classified into one of a series of hydrostatic design bases (HDB) in accordance with ASTM D2937. For example, the HDB of a PE3408 piping material is 1600 pounds per square inch (PSI) at 73.4F. This provides a HDS of 800 psi at the same temperature.

If the temperature of PE pipe is exposed to rises or decreases, the pressure capability of the pipe varies. When the temperature exceeds 73.4F. the ratio of outside diameter to wall thickness decreases the LTHS. However, if the temperature is lowered, the LTHS rises. The HDS also rises as the temperature drops below 73.4F. A rise in temperature will decrease the modulus of elasticity. Embrittlement of the pipe material is a concern when extremely low temperatures are experienced. It is true, however, that many types of PE materials have been tested at extremely low temperatures without showing any signs of embrittlement.

Expansion

Expansion and contraction are always considerations when working with plastic pipe. These same factors are in play with metal and concrete pipe. PE pipe can expand up to 10 times more than metal or concrete. On the surface, this can appear to be a strike against PE pipe. However, while PE pipe will expand much more than metal or concrete, or even vitrified clay pipe, the modulus of elasticity for the plastic pipe is much lower than it is for the other types of pipe. CPVC expansion loop specifications are shown in Table 5.3. Offsets and changes in direction are shown in Table 5.4.

What does all of this mean? PE pipe is likely to move more when exposed to temperature extremes, but the stress on the plastic pipe will be substantially less, and this is a good thing. The bottom line is that PE pipe is a good choice for above-ground installations and it is an economically-wise choice.

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TABLE 5.3 CPVC Expansion Loops

CPVC		Length of Run (feet)									
		10	20	30	40	50	60	70	80	90	100
Pipe Size (in.)	O.D. of Pipe (in.)	Minimum Deflected Pipe Length (DPL) (inches)									
1/2	0.840	15	21	26	30	33	36	39	42	44	47
3/4	1.050	17	23	29	33	37	40	44	47	50	52
1	1.315	18	26	32	37	41	45	49	52	55	58
1 1/4	1.660	21	29	36	42	46	51	55	59	62	66
1 1/2	1.900	22	31	39	44	50	54	59	63	67	70
2	2.375	25	35	43	50	56	61	66	70	75	79
3	3.500	30	43	52	60	67	71	80	85	91	95
4	4.500	34	4	59	68	77	84	91	97	103	108
6	6.625	42	59	72	83	93	102	110	117	125	131
8	8.625	47	67	82	95	106	116	125	134	142	150
10	10.750	53	75	92	106	118	130	140	150	159	167
12	12.750	58	81	100	115	129	141	152	163	173	182

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TABLE 5.4 CPVC Offsets and Change of Direction

CPVC		Length of Run (feet)									
		10	20	30	40	50	60	70	80	90	100
Pipe Size (in.)	O.D. of Pipe (in.)	Minimum Deflected Pipe Length (DPL) (inches)									
1/2	0.840	21	30	36	42	47	51	55	59	63	66
3/4	1.050	23	33	40	47	22	57	62	66	70	74
1	1.315	26	37	45	52	58	61	69	74	78	83
1 1/4	1.660	29	42	51	59	66	72	78	86	88	93
1 1/2	1.900	31	44	54	63	70	77	83	89	94	99
2	2.375	35	50	61	70	79	86	93	99	105	111
3	3.500	43	60	74	85	95	105	113	121	128	135
4	4.500	48	68	84	97	108	119	128	137	145	153
6	6.625	59	53	102	117	131	144	155	166	176	186
8	8.625	67	95	116	134	150	164	177	189	201	212
10	10.750	75	106	130	150	167	183	198	212	224	237
12	12.750	81	115	141	163	182	200	216	230	244	258

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Ultraviolet Effects

Ultraviolet effects on PE pipe can degrade the material. This is easy enough to overcome. The secret is to use a PE pipe that contains a minimum of 2 percent carbon black. If you must use non-black pipe, check with the manufacturer for recommendations in regards to the effects of ultraviolet rays.

Durability

PE pipe is extremely durable and is often used to convey chemical-based products. The pipe will not rust or corrode. Neither chemical, electrolytic, or galvanic action will cause PE pipe to rot or pit. Some strong oxidizing agents, such as sulphric or nitric acids, can cause problems for PE piping. Hydrocarbons, such as fuel oils and diesel fuels pose threats to PE pipe.

Extended exposure to strong oxidizing agents can lead to crack formation or crazing on the pipe surface. PE pipe that is exposed to hydrocarbons for extended periods of time can reduce the pressure capability of the pipe. You might notice swelling in a PE pipe that has had extended exposure to hydrocarbons. Reduced tensile strength is another side effect of long-term exposure to hydrocarbons. In time, the hydrocarbons may eat through the pipe and result in leaching of the material being conveyed through the pipe. Before installing PE pipe that will have long-term exposure to hydrocarbons or strong oxidizers you should consult the pipe manufacturer for recommendations.

EXTERNAL DAMAGE

External damage is a potential risk for any type of exposed piping. Pipe must be protected from be flattened out, gouging, and deflecting. When pipe is installed in a high-traffic area or any other location where the risk of damage is higher than normal, extra protection must be provided for the pipe. Some situations will allow the pipe to be protected by the construction of a berm. In other cases, the pipe must be encased in a protective covering.

In the event PE pipe is damaged, it may have to be replaced. If the pipe is gouged in excess of 10 percent of its minimum wall thickness, the pipe should be replaced. When PE pipe has been flattened or deflected, watch for stress-whitening, crazing, cracking, and any other visible signs of damage. If any of these conditions appear, replace the section of pipe that is affected.

INSTALLING PE PIPE ON GRADE

There are two ways to install PE pipe above ground. You can install it by laying it on top of the ground, or you can install it on some type of designed support.

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Laying the pipe directly on the ground is known as installing it on grade. The pipe might be laid in an unrestrained method. This means draping the pipe over the ground and leaving it alone. Temperature changes will result in expansion and contraction, but this will not be a concern in an unrestrained system. However, if there is concern that the pipe may move too much, it can be anchored to the ground to control the range of motion.

PE pipe that is laid unrestrained on grade is usually laid in a snaking fashion. This allows slack in the pipe to account for contraction. The surface on which the pipe is laid must be clear of any obstacles that might damage the pipe. When there are temperature changes, the pipe will move. Any movement of the pipe over sharp or abrasive surfaces is likely to result in pipe damage.

Pipe installations have a beginning and an end. Both are usually fixed connections. It is not wise to make fixed connections at the end of unrestrained pipe runs. You should stabilize the pipe run when it approaches a fixed connection. The distance from the fixed location to stabilize should be a minimum of 3 pipe diameters away from the rigid connection. By doing this, the stress-concentrating effect of lateral pipe movement at the fixed connection is controlled. A consolidated earthen berm makes an effective stabilizer.

ANCHORED PIPE RUNS

Anchored pipe runs are desirable when too much pipe wandering will create problems. There are many methods of retention available They include:

- Earthen berms
- Pylons
- Augered anchors
- Concrete cradles
- Thrust blocks

If you elect to use earthen berms to restrain an above-ground installation, you have two options. The pipe can be covered continuously with a light layer of earth. Or, you can use earth at specific intervals to hold the pipe in place. A continuous layer of earth is not only very effective in restraining pipe movement, it also provides a level of protection for the pipe from temperature fluctuations. When the temperature is more stable, so is the pipe. Securing pipe with earth at selected intervals is less expensive that covering the pipe with a full coat of earth. When this method is used, the earth should encase the pipe for a distance equal to one to 3 pipe diameters.

Pipe that is anchored at specific intervals will deflect laterally when temperatures fluctuates. What is an acceptable spacing pattern for interval supports? It is generally thought that the spacing of support intervals is based on economics. On occasions when lateral deflection must be seriously controlled, the distance between

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supports must be reduced. The greater the distance between supports, the greater the lateral movement. Of course, you must also pay attention to the maximum allowable lateral movement allowable for the type of pipe being secured.

INSTALLING PE PIPE ABOVE GRADE

When installing PE pipe above grade, you must still consider lateral movement. In addition to this, you must take into consideration beam deflection and the support or anchor configuration. The spacing of supports for above-grade, suspended or supported pipe depends upon simple-beam or continuous-beam analysis. Spacing of supports is based on limiting bending stress.

If excessive temperature ranges are expected, PE pipe should be supported continuously. Any support that simply cradles a pipe, rather than gripping it, should be at least one-half to one pipe diameter in length and should support at least 120 degrees of the pipe diameter. Of course, no support should subject the plastic pipe to sharp or abrasive surfaces.

When supports are used for PE pipe, they should have enough strength to restrain the pipe from lateral or longitudinal deflection under anticipated service conditions. Supports intended to offer free movement of pipe during expansion must provide a guide without restraint in the direction of movement. A support designed to grip a pipe firmly must offer either a flexible mount or have adequate strength to stand up under anticipated stresses. PVC expansion loop specifications are shown in Table 5.6. PVC offsets and changes of direction are illustrated in Figure 5.6.

Any heavy fitting, valve, or flanges must be fully supported and restrained for a distance of at least one full pipe diameter. Such fittings, valves, and flanges are considered to be rigid structures. Any rigid structure in a flexible pipe system should be fully isolated from bending stresses associate with beam sag or thermal deflection. Some of the typical pipe hanger types include: pipe stirrup supports, clam shell supports, and suspended I-beam or channel continuous supports.

FOLLOWING INSTRUCTIONS

The key to a successful pipe installation lies in following instructions and knowing how to work the specific material being installed. Manufacturers are very willing to provide designers and contractors with a wealth of information about plastic products.

Many professional organizations offer extensive research data that proves helpful to both designers and installers. The data exists and is accessible. Anyone with an intent to make a safe and successful pipe installation can find plenty of information to work with.

Contractors and installers can usually rely on drawings and specifications provided by designers. When designers run into questionable areas, they can turn to

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TABLE 5.5 PVC Expansion loops

PVC Expansion Loops

PVC		Length of Run (feet)									
		10	20	30	40	50	60	70	80	90	100
Pipe Size (in.)	O.D. of Pipe (in.)	Minimum Deflected Pipe Length (DPL) (inches)									
1/2	0.840	11	15	19	22	24	27	29	31	32	34
3/4	1.050	12	17	21	24	27	30	32	34	36	38
1	1.315	14	19	23	27	30	33	36	38	41	43
1 1/4	1.660	15	22	26	30	34	37	40	43	46	48
1 1/2	1.900	16	23	28	33	36	40	43	46	49	51
2	2.375	18	26	32	36	41	45	48	51	55	58
3	3.500	22	31	38	44	49	54	58	62	66	70
4	4.500	25	35	43	50	56	61	66	71	75	79
6	6.625	30	43	53	61	68	74	80	86	91	96
8	8.625	35	49	60	69	78	85	92	98	104	110
10	10.750	39	55	67	77	87	95	102	110	116	122

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TABLE 5.6 PVC Offsets and Change of Directions

PVC Offsets and Change of Directions

PVC		Length of Run (feet)									
		10	20	30	40	50	60	70	80	90	100
Pipe Size (in.)	O.D. of Pipe (in.)	Minimum Deflected Pipe Length (DPL) (inches)									
1/2	0.840	15	22	27	31	34	37	41	43	46	48
3/4	1.050	17	24	30	34	38	42	45	48	51	54
1	1.315	19	27	33	38	43	47	51	54	57	61
1 1/4	1.660	22	30	37	43	48	53	57	61	65	68
1 1/2	1.900	23	33	40	46	51	56	61	65	69	73
2	2.375	26	36	45	51	58	63	68	73	77	81
3	3.500	31	44	54	62	70	77	83	88	94	99
4	4.500	35	50	61	71	79	87	94	100	106	112
6	6.625	43	61	74	86	96	105	114	122	129	136
8	8.625	49	69	85	98	110	120	130	139	147	155
10	10.750	55	77	95	110	122	134	145	155	164	173
12	12.750	60	84	103	119	133	146	158	169	179	189

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plastic manufacturers. There is no excuse for failure when there is so much material available to ensure success.

This chapter has provided solid, basic information about the installation of above-ground piping systems. There are, of course, numerous options in the design and construction of above-ground pipelines.

The Internet is an invaluable source of information. Web sites include consultants, manufacturers, contractors, professional organizations, professional bulletin boards, newsgroups, and more. On the local level, you can talk with suppliers and distributors. Code officials are often helpful in resolving questions about an installation. My experiences have shown that code officers are very receptive to legitimate questions about the code. In many cases, local designers and contractors will share information with other professionals.

In general, contractors and installers should be able to turn to the designers of systems to be installed. Designers can talk with manufacturers to obtain product information, formulas, and other detailed information. Don't be afraid to ask questions. It is far better to seek competent answers than it is to make costly mistakes. A little research can go a long way in the development of a successful piping system.

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Source: PLASTIC PIPING HANDBOOK

CHAPTER 6
BURIED PIPE DESIGN

Plastic pipe is an ideal material for underground use. Corrosion can be a problem with metal pipe, but plastic pipe is not subject to corrosion. Plastic pipe is light in weight and cost-effective. Throw in the fact that plastic pipe is easy to join together and you've got the best choice for buried pipe installations. For everything from water services for individual homes to sewers to major pipelines, plastic pipe is the answer. And, there are plenty of types of plastic pipe available for underground use.

If there is a complaint against using plastic pipe below grade, it is that the pipe is hard to identify once it is buried. This can cause trouble when excavation is done around the pipe after installation. It is said that most pipeline damage occurs as a result of accidental contact when excavating. With this being the only major drawback to installing plastic pipe underground, you can see why plastic installations are so popular. The problems associated with locating buried plastic pipe can be overcome by installing conductive wire next to the pipe in a trench. Then electronic instruments can pick up a signal from the wire to identify the location of the pipeline.

There are two basics methods for installing plastic pipe in trenches. Pipe with a large diameter is usually joined above ground and then lowered into a narrow trench. Smaller pipe, usually pipe with a diameter up to 8 inches, is often joined in a trench. This requires a much wider trench and it means that installers must be in the trench. When this is the case, appropriate safety procedures must be employed to protect the workers from trench failure and cave-ins. Before we get into deep details, let's discuss the basics of an underground installation.

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PRELIMINARY WORK

There is preliminary work required before pipe can be installed below grade. Material must arrive on site. Once the material has been unloaded and stored properly, the site is ready for work. Sometimes a trench is dug prior to pipe being put in the vicinity. Since open trenches pose some threat, most contractors prefer to have pipe, fittings, and other installation supplies close at hand, so that the pipe installation can proceed quickly and allow the trench to be closed as soon as possible.

If you are stocking a job where the trench has not yet been dug, you should position the pipe and other materials far enough away from the trench path to ensure that the materials will not be damaged by the trenching process. When laying out the pipe in the trench area, this is know as stringing, string it so that the socket ends are pointing in the direction that the work will be progressing.

When stringing pipe along an open trench, place the pipe as close to the trench as is reasonably possible. This will expedite work once the joining process begins. Some regions suffer from vandalism. It is sad but true that job sites do come under attack from vandals and thieves. If you are stringing material that will be left unattended, you should not string more material than what you must in order to keep crews busy while more materials are brought into place.

DIGGING

The digging of trenches must be accomplished before pipe can be installed below ground. Trench depths vary widely. The type of piping application can also affect the trenching process. For example, a pipeline that is going to be pressurized, such as a water main, does not require a trench that has a set grade on its bed. In contrast, a trench for a sewer will require a steady grade to allow for a gravity flow through the pipe. The width of a trench is also a factor as illustrated in Figure 6.1.

As stated earlier, pipe with a diameter of 8 inches or less is sometimes installed by workers who are inside the trench. Naturally, this requires a much wider trench. When a backhoe, crane, or other lifting equipment will be used to lower pre-joined plastic pipe into a trench, the width of the trench can be much narrower. It is not uncommon for this type of trench to be no wider than 3 times the diameter of the pipe being installed.

Safety is a top concern with any trenching operation. No corners should be cut when it comes to protecting workers and the public in regards to open trenches. This may mean installing highly visible barriers to avoid accidents around a trench. It is common to put proper shoring equipment in place prior to allowing workers to enter a deep trench. The purpose of this chapter is not to explore and expound on all safety requirements for trenching, but it is a major factor in the development of an underground piping system.

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BURIED PIPE DESIGN

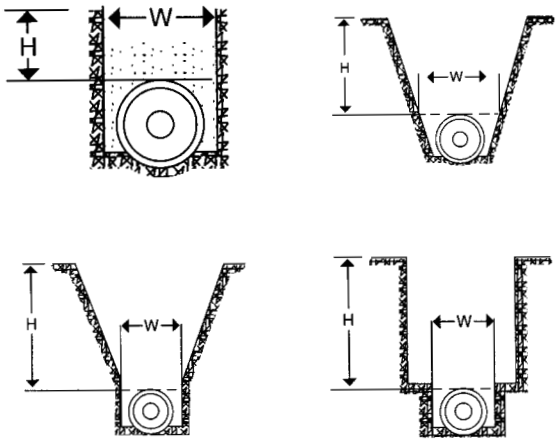

FIGURE 6.1 Trench widths for PVC pipe. *(Courtesy George Fischer Engineering Handbook)*

THE BED

The bed of a trench must be prepared properly to accept the installation of plastic pipe. A first concern is to make sure that the trench bed is continuous, fairly smooth, and free of rocks and other objects that might damage pipe or fittings placed in the trench. In the case of a gravity-type pipeline, the trench bed must be dug to an appropriate grade factor. Having a solid trench bed is another major consideration. It is not acceptable to have a bed that may sink in some sections after an installation is backfilled. There are times when natural obstacles are encountered that are not practical to remove. Examples of this could include ledge or bedrock and large boulders. Blasting these obstacles out of the trench may not be necessary. However, plastic pipe should never be installed in a manner in which the pipe makes contact with rocks or other abrasive materials.

To overcome bedrock and boulders that do not have to be removed, it is possible to install a softer surface over the rock. Sand is a good solution, but earth can also be used. It is not, however, acceptable to simply dump sand or dirt in on top of the rock and spread it out. The padding material must be compacted. A rule-of-thumb is to install 4 to 6 inches of padding material over the rock. Once the padding material, the sand or earth, is compacted properly, it will protect the pipe from direct contact with objects that may damage the pipe. It may be necessary to install the padding in layers and to compact each layer as it is installed. For example, you may find that the best job can be done by installing a 3-inch layer of sand and compacting it prior to installing an additional 3 inches of sand that will then also be compacted.

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BURIED PIPE DESIGN

Trenches that are to be dug on a specific grade must be checked periodically as the trench is dug to ensure that the grade is being maintained. During the digging process it is common for digging errors to occur and for obstacles to require removal. This can compromise the steady grade of the trench. However, there are ways to overcome these problems.

Assume that you are having a trench dug for a sewer that requires a steady downstream grade of one-eighth of an inch per foot. The equipment operator is very experienced and is doing a good job. But then a large rock is encountered that needs to be removed. When the rock is removed it will leave a hole in the trench bed. It is not acceptable to install pipe over the hole. If this were done, the pipe would not have continuous support. So, how do you fix the hole and maintain the grade of the trench? If necessary, you excavate the hole to make it large enough to work with. Then you begin filling it with sand or dirt. Fill the hole in layers and compact each layer prior to placing a new layer. The compacted fill will come up to the bed level of the trench and you will no longer have a problem.

PLACING PIPE

Placing pipe in a trench may be done in a number of ways. The method of placement depends on the type of trench being used.

When a wide trench is used, with workers in the trench, pipe is often passed from workers above the trench to workers in the trench. Pipe should never be rolled or tossed into a trench. Occasionally, pipe is lowered into this type of workplace with equipment, such as a backhoe. In all cases, the pipe should be handled carefully and laid in the trench gently.

Narrow trenches call for pipe to be assembled prior to installation in the trench. Due to this fact and the larger size of pipe normally installed in this manner, equipment is used to lower the pipe into the trench. Circumstances of a specific job can dictate the type of equipment that will be used. Backhoes and cranes are both used to lower assembled pipe into trenches. Telescoping lifting rigs are also used to lower pipe into trenches.

When equipment is used to lower assembled pipe sections, precautions must be taken to protect the pipe and the integrity of pipe joints. Standard procedure usually involves the use of rope or slings. The slings or rope should be positioned in a way to support the pipe sections adequately. At no time should pipe be rolled into a trench. It is important that the pipe not be twisted during the installation process. Improper handling can result in pipe damage and leaks.

THERMAL CONTRACTION

Thermal contraction is a consideration when installing plastic pipe in a trench. We talked about snaking pipe for above-ground installations in Chapter 5. Snaking is

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BURIED PIPE DESIGN

also used with underground pipe installations. Offsetting the pipe by snaking it is done to allow for thermal contraction. By increasing the length of the pipe by snaking it, you are providing additional pipe length to compensate for contraction. An exception to this rule is when you are working with pipe that is joined with O-rings. The O-ring connection allows for contraction within the O-ring. Pipe that is fused or solvent welded is the type of pipe that requires snaking. Figure 6.2 illustrates snaking pipe in a trench. Snaking length versus offset to compensate for thermal contraction is illustrated in Table 6.1.

AVOIDING BENDING AND STRESS

Avoiding bending and stress in a pipe system is a factor in the installation of plastic pipe. Unlike steel pipe, plastic pipe is not intended to support heavier weights, such as valves, anchors, and so forth. Plastic pipe is designed to support soil loads and internal pressures up to a specified hydrostatic pressure rating. When accessories are placed in the pipeline, such as valve boxes, the accessories must be supported to prevent additional bending and stress on the plastic pipe.

THRUST BLOCKS

Concrete thrust blocks are used to anchor plastic pipelines. It is not acceptable for plastic pipe to be in direct contact with concrete or other abrasive materials. When a concrete thrust block is used, the pipe must be protected from the concrete. Wrapping the pipe with rubber, or some other suitable sleeve, to prevent direct contact with the concrete is necessary.

Axial movement may be a cause for pipe restriction. When this is the case, it is common to apply split collars around the outside diameter of the pipe with solvent-welded joints to protect the pipe from contact with concrete. It is recommended that the solvent-welded joints between the collars and the pipe exterior be allowed to dry for at least 48 hours prior to pouring concrete in the area.

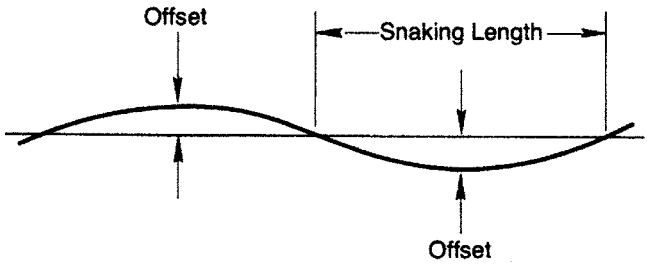

FIGURE 6.2 Snaking pipe in a trench. *(Courtesy George Fischer Engineering Handbook)*

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TABLE 6.1 Snaking Length vs. Offset (in inches) to Compensate for Thermal Contraction

Snaking Length, (ft.)	Maximum Temperature Variation (°F) Between Time of Cementing and Final Backfilling									
	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
	Loop Offset, (in.)									
20	2.5	3.5	4.5	5.20	5.75	6.25	6.75	7.25	7.75	8.00
50	6.5	9.0	11.0	12.75	14.25	15.50	17.00	18.00	19.25	20.25
100	13.0	18.0	22.0	26.00	29.00	31.50	35.00	37.00	40.00	42.00

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BURIED PIPE DESIGN

VERTICAL PIPE SECTIONS

Vertical pipe sections, also known as risers, are sometimes installed in underground piping systems. In the case of sewers, risers will come to the surface at grade level and will be fitted with a cleanout fitting and plug. This allows the pipe to be rodded out if an obstruction occurs in the pipe and blows sewage flow. Risers should not be installed to support above-ground metal valves or other heavy objects. The stress on the exposed pipe may prove to be more than the pipe can withstand.

When vertical pipe sections rise above grade they are exposed to the risk of impact and damage. Protection of such piping is in order. Such protection could come in the form of an enclosed box or area around the pipe. Another method of protection might be the installation of a metal pipe sleeve over the plastic pipe. If this is done, the metal pipe must have a smooth interior and it must be properly supported to withstand impact. Another consideration in exposed risers is the risk of excessive heat, such as sunlight, degrading the pipe material to a dangerous point.

PLOWING

Plowing pipe into a trench is a cost-effective means of installation when practical. If a job lends itself to having the pipe plowed into a trench, the time required to make an installation can be reduced greatly. Plastic pipe that is subject to hot temperatures should not be plowed. High temperature weakens the pipe and opens the door to the risk of damage. Before pipe is plowed into a trench, the pipe should be tested for leaks. This is done with a low-pressure test to determine that all joints are sealed satisfactorily to maintain the pipe's full hydrostatic pressure rating.

Plowing is not to be confused with pulling. Assembled pipe should never be pulled into a trench. A tractor is used to plow pipe into trenches. The tractor is fitted with a plowing chute that the pipe is fed through. This chute is located on the rear of a plow blade. A plow chute must be sized appropriately for the size of the pipe being installed. When this method is available and suitable, it is well worth considering.

BACKFILLING

The backfilling of a trench is not as simple as taking a bulldozer and pushing mounds of earth in on top of the pipe. In fact, the backfilling process is a critical part of a pipeline installation. Done improperly, backfilling can damage buried pipe in many ways. Sharp objects, such as rocks, can cut a pipe. Heavy loads of dirt dumped on some types of pipe can crimp or collapse the pipe. This is especially true when the pipe is subjected to hot temperatures and become softer than normal. Once a pipe is installed in a trench and is ready for backfilling, it is a good idea to put

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some pressure in the pipeline. A pressure of just 25 psi can help in keeping a pipe from collapsing during the backfilling process.

Backfill material should be checked before it is used. If the fill material contains rocks, pieces of concrete, or other items that might damage the pipe, don't use it. Backfill material should be free of debris and suitable for satisfactory compaction. The first layer of backfill material shouldn't be more than about 6 inches in depth. Get this layer in the trench and compact it to protect the pipe as more backfilling is done. In many cases, the trench will continue to be covered with similar layers of backfill that will be compacted before new layers are added. Large loads of backfill should not be pushed into a trench until the pipe is fully protected with an adequate depth of compacted fill to accept the weight of the larger loads without damaging the pipe.

GENERAL DESIGN PROCEDURE

One of the first steps in designing a buried pipeline is determining dead loads and surcharge loads. Other factors that come into play include prism loads, soil arching, Marston loads, soil creep, distributed loads, and more. Let's look at these design factors individually.

Dead Load

A dead load is the load that is applied to a pipeline at all times. This includes the weight of soil on top of the pipe. In addition to the weight of soil, the weight of any other permanent load over a pipe is considered a dead load. An example of this could be the pavement of a highway that passes over a pipeline.

Since polyethylene pipe (PE) is such a common plastic pipe, let's talk about dead loads and PE pipe. The overburden load applied to the pipe crown is usually considered to be equal to the weight of the soil column that projects above the pipe. A soil column of this type is often called a prismatic element and is involved in the use of a prism load.

Prism Load

A convention used to calculate the earth pressure on a pipe when estimating vertical defection is the prism load. The true load transmitted to a pipe from soil mass is subject to the stiffness of the soil and the pipe. The prism load may be deceiving when working with flexible plastic pipe. In reality, the load applied to such a pipe can be considerably less than the prism load might show. This is because the shear resistance transfers part of the soil load directly above the pipe into the trench sidewalls and the embedment. This process is called arching. For an accurate assess-

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BURIED PIPE DESIGN

ment, designers frequently use both the prism load and the Marston method to determine the proper design for buried pipe.

The simple way to determine vertical earth load on a horizontal pipe in a mass of soil is when the soil has uniform stiffness and weight throughout. This assumes that there are no large voids or buried structures in the area of the pipe. Under these conditions, the vertical earth pressure acting on a horizontal pipe at a depth is equal to the prism load per unit area.

$$\text{Prism Load, } P_E = wH$$

where PE = vertical soil pressure, lb/ft^2
w = unit weight of soil, lb/ft^3
H = soil height above pipe crown, ft

Arching

As already discussed, PE pipe rarely shares the same stiffness as the soil encasing it. This throws off the results of calculations made using the prism load. The load could be more or less than the results of the calculations would indicate. In the case of PE pipe, and most flexible plastic pipe, the soil above the pipe disperses its load away from the pipe and into the soil beside the pipe. This is arching. Think of arching as the difference between the applied load and the prism load.

When there is a reduction in vertical load, you have arching. If the vertical load is more than the prism load, you have reverse arching. The downward movement of backfilled soil is what causes arching. Pipe deflection can initiate the arching process. Any compression of deeper layers of backfill or any settlement in a trench bed can be responsible for arching. In the case of plastic pipe, vertical deflection of the pipe crown is usually what starts the arching process.

Arching is generally permanent. It occurs in most stable applications. The arching is maintained by soil shear stresses. When large vibrating machines operate over a pipeline the arching may not be permanent. This is also true of situations where there is light cover over the buried pipe. Soft and unstable backfill can also prevent permanent arching. Any pipeline placed under roadways may not experience permanent arching.

Marston Load

The Marston load is generally used along with the prism load when working with plastic pipe installations and design. A more realistic value can usually be obtained for plastic pipe when the Marston load is used. This method dates back to 1930 and has proved itself within the industry. A review of ASCE Manual No. 60 will reveal more on the method.

$$\text{Marston Load, } P_M = C_D w B_D$$

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where terms are previously defined, and

e = natural log base number, 2.71828

K = Rankine earth pressure $\tan^2\left(45 - \frac{\phi}{2}\right)$

ϕ = Internal friction angle, degrees
H = Soil cover height, feet
u' = Soil cover height, feet

Typical Ku' values are:

Saturated Clay	0.110
Ordinary Clay	0.130
Saturated Top Spoil	0.150
Sand and Gravel	0.165

Loads applied to pipes in embankments are generally higher than they would be on pipes in trenches. Actual load depends on the relative stiffness between the embankment soil and the pipe. The prism load is most often used when pipe is to be placed in an embankment. By using the prism method, the vertical pressure on flexible pipe in an embankment can be calculated.

Soil Creep

When backfill material consists of cohesionless soil and analytical methods are not available for precise calculations, designers don't normally factor in soil creep. Plastic pipe tends to creep faster than cohesionless soil.Clayey soil can creep much more than cohesionless soil. This is especially true if the clay is saturated. Arching can be high when clayey soil is used as a backfill material. The soil creep moves more soil towards the buried pipe. A conservative design approach is called for under these conditions. This means that a low friction angle is used when working with the Marston equation. It's common for a factor of a 11-percent angle to be assigned to ordinary clay and an angle of 8-percent to be used for saturated clay.

Surcharge Loads

Surcharge loads are often temporary loads, but they can be permanent loads. Any load created by a structure or a vehicle can be considered a surcharge load. In the case of vehicular loads, they are called live loads. There are many types of potential surcharge loads. A footing or foundation for a building is considered a surcharge load. Point loads, as they are called, can be from the tires from vehicles. Any of these loads can be distributed through soil in a way that reduces pressure with an increase in depth of horizontal distance from the surcharged area.

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Common design practice is to equate the load on a buried pipe from a surcharge load with the downward pressure acting at the plane of the pipe crown. When the surcharge load is determined, the total load acting on the pipe is the sum of the earth load and the surcharge load.

Wall Compressive Strength

Compressive thrust can occur in the wall of a non-pressurized pipe that is confined in a dense embedment. This happens when the pipe is subjected to a radially directed soil pressure. When there is compressive stress within the pipe wall it can create internal pressure. Physical properties of PVC and CPVC are shown in Table 6.2.

Radial soil pressure that is resulting in stress is no usually uniform. Interestingly enough, it is generally assumed that the radial soil pressure is uniform and equal to the vertical soil pressure at the crown of a pipe. It's very possible for buried pressure pipe to have an internal pressure greater than the radial external pressure applied by the soil. Therefore, wall compressive stress is rarely factored in when working with pressurized pipe. Thermodynamic properties of PVC and CPVC pipe are shown in Table 6.3.

Shallow Cover

When shallow cover is provided over a plastic pipe, there are design factors that must be taken into consideration. For example, will floatation of the pipe, due to shallow cover, become a problem? Will there be upward buckling due to flooding? How likely is it that a high groundwater table will float the pipe? Will the pipe be adversely affected by live loads?

How much cover is enough? This depends on the type of pipe being installed and the job conditions that the pipe will be subjected to. A rule-of-thumb cover depth is enough cover material to equal at least the height of the pipe diameter, or 18 inches, whichever is greater. It is generally accepted that there should never be less than 12 inches of cover over a pipe.

GROUNDWATER

Groundwater can cause buried pipe to float. This is especially true when shallow cover is applied and when the cover material is light in weight. Floatation is much more likely when working with plastic pipe. Flooding and high water tables can float plastic pipe when the water produces a force greater than the downward force of the soil prism above the pipe. Pipe weight and the weight of its contents are also a factor.

Flooding can cause some types of soil to lose cohesiveness. This, too, can result in upward movement of a pipe. Any long-term ground saturation can cause a

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TABLE 6.3 Thermodynamics of PVC and CPVC Thermoplastic Materials

Properties	Unit	PVC	CPVC	Remarks	ASTM Test
Coefficient of Thermal Linear Expansion per °F	in/in/°F	2.8×10^{-5}	3.4×10^{-5}		D-696
Thermal Conductivity	BTU/hr/ft²/°F/in	1.3	0.95	Average Specific Heat of 0-100°C	C-177
Specific Heat	CAL/g/°C	0.20-0.28		Ratio of Thermal Capacity to that of Water at 15°C	
Maximum Operating Temperature	°F	140	210	Pressure Rating is Directly Related to Temperature	
Heat Distortion Temperature @ 264 PSI	°F	158	217	Thermal Vibration and Softening Occurs	D-648
Decomposition Point	°F	400+	400+	Scorching by Carbonization and Dehydrochloration	

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TABLE 6.2 Physical Properties of Rigid PVC and CPVC Thermoplastic Materials

The following table lists typical physical properties of PVC and CPVC thermoplastic materials. Variations may exist depending on specific compounds and product.

Mechanical

Properties	Unit	PVC	CPVC	Remarks	ASTM Test
Specific Gravity	g/cm³	1.40 ± .02	1.55 ± .02		D-792
Tensile Strength @ 73°F	PSI	7,200	8,000	Same in Circumferential Direction	D-638
Modules of Elasticity Tensile @ 73°F	PSI	430,000	360,000	Ratio of Stress on Bent Sample at Failure	D-638
Compressive Strength @ 73°F	PSI	9,500	10,100		D-695
Flexural Strength @ 73°F	PSI	13,000	15,100	Tensile Stress on Bent Sample at Failure	D-790
Izod Impact @ 73°F	Ft-Lbs/In of Notch	1.0	1.5	Impact Resistance of a Notched Sample to a Sharp Blow	D-256
Relative Hardness @ 73°F	Durometer "D" Rockwell "R"	80 ± 3 110-120	— 119	Equivalent to Aluminum —	D-2240 D-785

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reduction in soil support for a pipe. These conditions can result in pipe buckling from external hydrostatic pressure.

Pipelines that are installed over groundwater are less prone to buckling, due to design considerations prior to the installation. When pipelines run full of liquid at all times they are less likely to float and buckle. Most designers agree that floatation is unlikely when a pipe is buried in common saturated soil with a cover depth equal to at least one-and-one-half times the pipe diameter.

MANHOLES

Manholes installed in conjunction with pipelines are at more risk to floatation than the piping is. Since manholes are attached to vertical risers and don't have cover, they are much more vulnerable to floatation. A solution to this problem can be as simple as the installation of manhole anti-floatation anchors. These anchors are made with reinforced concrete. The concrete slabs are placed over manhole stub-outs. Once the concrete is in place, its weight offsets the risk of floatation.

DESIGNING FOR A WATER ENVIRONMENT

Pipe systems installed in a water environment require design consideration for external hydraulic pressure, submergence weighting, and floatation. Any river, lake or stream crossing is considered a water environment. Wetlands and marshes are also considered water environments.

The flattening of pipes carrying gasses and pipes that are carrying partial loads of liquids are a concern when the internal pressure of a pipe is less than the static external hydraulic load. Flattening is usually not a concern for outfall and intake lines. When pipe ends are open the pressure is balanced. Water and wastewater pipelines that pass under water are protected due to the static head in the full pipe.

UNCONSTRAINED BUCKLING

Unconstrained buckling of pipe walls can occur when excessive external pressure is encountered.

This causes a flattening of a pipe. Stiffness is the factor involved in the maximum external load capacity. Material strength might seem like the proper factor, but stiffness is the true variable. Pipes will flatten when the bending moment, due to the load, exceeds the resisting moment due to elastic stresses in the pipes. To determine the critical external pressure above which a round pipe will flatten you can use the Love's equation.

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TABLE 6.4 Friction Loss in Equivalent Feet of Pipe for Schedule 80 Thermoplastic Fittings

Feet of Pipe — Schedule 80 Thermoplastics Fittings

Nominal Pipe Size, In.	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	6	8
Tee, Side Outlet	3	4	5	6	7	8	12	15	16	20	22	32	38
90° Ell	1 1/2	1 1/2	2	2 3/4	4	4	6	8	8	10	12	18	22
45° Ell	3/4	3/4	1	1 3/8	1 3/4	2	2 1/2	3	4	4 1/2	5	8	10
Insert Coupling	—	1/2	3/4	1	1 1/4	1 1/2	2	3	3	—	4	6 1/4	—
Male-Female Adapters	—	1	1 1/2	2	2 3/4	3 1/2	4 1/2	—	6 1/2	—	9	14	—

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TABLE 6.5 Friction Loss in Schedule 40 Pipe

Carrying Capacity and Friction Loss — Schedule 40 Thermoplastics Pipe

Independent variables: Gallons per minute and nominal pipe size O.D. (Min. I.D.)
Dependent variables: Velocity, friction head and pressure drop per 100 feet of pipe, interior smooth.

GALLONS PER MINUTE	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH
		½ in.			**¾ in.**			**1 in.**			**1¼ in.**			**1½ in.**			**2 in.**			**3 in.**	
1	1.13	2.08	0.90	0.63	0.51	0.22															
2	2.26	4.16	1.80	1.26	1.02	0.44	0.77	0.55	0.24	0.44	0.14	0.06	0.33	0.07	0.03						
5	5.64	23.44	10.15	3.16	5.73	2.48	1.93	1.72	0.75	1.11	0.44	0.19	0.81	0.22	0.09	0.49	0.066	0.029	0.30	0.015	0.007
7	7.90	43.06	18.64	4.43	10.52	4.56	2.72	3.17	1.37	1.55	0.81	0.35	1.13	0.38	0.17	0.69	0.11	0.048	0.49	0.021	0.009
10	11.28	82.02	35.51	6.32	20.04	8.68	3.86	6.02	2.61	2.21	1.55	0.67	1.62	0.72	0.31	0.98	0.21	0.091	0.68	0.03	0.013
15		**4 in.**		9.48	42.46	18.39	5.79	12.77	5.53	3.31	3.28	1.42	2.42	1.53	0.66	1.46	0.45	0.19	1.03	0.07	0.030
20	0.51	0.03	0.013	12.65	72.34	31.32	7.72	21.75	9.42	4.42	5.59	2.42	3.23	2.61	1.13	1.95	0.76	0.33	1.37	0.11	0.048
25	0.64	0.04	0.017		**5 in.**		9.65	32.88	14.22	5.52	8.45	3.66	4.04	3.95	1.71	2.44	1.15	0.50	1.71	0.17	0.074
30	0.77	0.06	0.026	0.49	0.02	0.009	11.58	46.08	19.95	6.63	11.85	5.13	4.85	5.53	2.39	2.93	1.62	0.70	2.05	0.23	0.10
35	0.89	0.08	0.035	0.57	0.03	0.013				7.73	15.76	6.82	5.66	7.36	3.19	3.41	2.15	0.93	2.39	0.31	0.13
40	1.02	0.11	0.048	0.65	0.03	0.013				8.84	20.18	8.74	6.47	9.43	4.08	3.90	2.75	1.19	2.73	0.40	0.17
45	1.15	0.13	0.056	0.73	0.04	0.017		**6 in.**		9.94	25.10	10.87	7.27	11.73	5.08	4.39	3.43	1.49	3.08	0.50	0.22
50	1.28	0.16	0.069	0.81	0.05	0.022	0.56	0.02	0.009	11.05	30.51	13.21	8.08	14.25	6.17	4.88	4.16	1.80	3.42	0.60	0.26
60	1.53	0.22	0.095	0.97	0.07	0.030	0.67	0.03	0.013				9.70	19.98	8.65	5.85	5.84	2.53	4.10	0.85	0.37
70	1.79	0.30	0.13	1.14	0.10	0.043	0.79	0.04	0.017							6.83	7.76	3.36	4.79	1.13	0.49

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TABLE 6.5 *(continued)* Friction Loss in Schedule 40 Pipe

GALLONS PER MINUTE	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH	VELOCITY FEET PER SCOND	FRICTION HEAD FEET	FRICTION LOSS POUNDS PER SQUARE INCH
							8 in.			**10 in.**			**12 in.**		
75	1.92	0.34	0.15	1.22	0.11	0.048	0.84	0.05	0.022				7.32	8.82	3.82	5.13	1.28	0.55
80	2.05	0.38	0.16	1.30	0.13	0.056	0.90	0.05	0.022				7.80	9.94	4.30	5.47	1.44	0.62
90	2.30	0.47	0.20	1.46	0.16	0.069	1.01	0.06	0.026				8.78	12.37	5.36	6.15	1.80	0.78
100	2.56	0.58	0.25	1.62	0.19	0.082	1.12	0.08	0.035	0.65	0.03	0.012	9.75	15.03	6.51	6.84	2.18	0.94
125	3.20	0.88	0.38	2.03	0.29	0.125	1.41	0.12	0.052	0.81	0.035	0.015				8.55	3.31	1.43
150	3.84	1.22	0.53	2.44	0.40	0.17	1.69	0.16	0.069	0.97	0.04	0.017				10.26	4.63	2.00
175	4.48	1.63	0.71	2.84	0.54	0.235	1.97	0.22	0.096	1.14	0.055	0.024					6.16	2.67
200	5.11	2.08	0.90	3.25	0.69	0.30	2.25	0.28	0.12	1.30	0.07	0.030	0.82	0.027	0.012		788	3.41
250	6.40	3.15	1.36	4.06	1.05	0.45	2.81	0.43	0.19	1.63	0.11	0.048	1.03	0.035	0.015		11.93	5.17
300	7.67	4.41	1.91	4.87	1.46	0.63	3.37	0.60	0.26	1.94	0.16	0.069	1.23	0.05	0.022			
350	8.95	5.87	2.55	5.69	1.95	0.85	3.94	0.79	0.34	2.27	0.21	0.091	1.44	0.065	0.028	1.01	0.027	0.012		
400	10.23	752	3.26	6.50	2.49	1.08	4.49	1.01	0.44	2.59	0.27	0.12	1.64	0.09	0.039	1.16	0.04	0.017		
450				7.31	3.09	1.34	5.06	1.26	0.55	2.92	0.33	0.14	1.85	0.11	0.048	1.30	0.05	0.022		
500				8.12	3.76	1.63	5.62	1.53	0.66	3.24	0.40	0.17	2.05	0.13	0.056	1.45	0.06	0.026		
750							8.43	3.25	1.41	4.86	0.85	0.37	3.08	0.28	0.12	2.17	0.12	0.052		
1000							11.24	5.54	2.40	6.48	1.45	0.63	4.11	0.48	0.21	2.89	0.20	0.087		
1250										8.11	2.20	0.95	5.14	0.73	0.32	3.62	0.31	0.13		
1500										9.72	3.07	1.33	6.16	1.01	0.44	4.34	0.43	0.19		
2000													8.21	1.72	0.74	5.78	0.73	0.32		
2500													10.27	2.61	1.13	723	1.11	0.49		

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$$P_{CR} = \frac{2E}{1 - \mu^2}\left(\frac{1}{DR - 1}\right)^3$$

where P_{CR} = critical flattening pressure, lb/in^2
E = elastic modulus, lb/in^2
μ = Poisson's Ratio
= 0.45 for polyethylene (long term)
DR = pipe dimension ratio

Pipe that is submerged in a body of water displaces its volume of the water. If the pipe and its contents are heavy enough, it will sink. Otherwise, it will float. In order to keep lightweight pipe submerged, the use of added weight is needed.

Most submergence weights are made with reinforced concrete. Since concrete forms can be made in various shapes, there is quite a bit of flexibility in the design and implementations of the weights.

Concrete weights are normally formed in two, or more, sections that clamp around a pipe over an elastomeric padding material. It is important that there be adequate clearance between weight sections to avoid the weights sliding along the pipe. Most weights are formed with flat bottoms and are bottom heavy. The reason for this design is to reduce rolling when cross-current conditions exist. Any fasteners used to secure weights to pipes must be approved for the intended use and must be resistant to the specific water environment.

DIFFERENT TYPES OF PIPE

Installation requirements for buried pipe vary with different types of pipe. For example, the installation methods for PE pipe can be very different than the requirements for PVC pipe. Installation details are covered in Chapter 7.

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Source: PLASTIC PIPING HANDBOOK

CHAPTER 7
PIPE HANDLING AND CONSTRUCTION

Conditions for pipe handling and construction vary depending upon the type of pipe being installed. For example, PVC pipe is often used for both drainage and water supply. The pipe design and installation for these two types of piping applications are different. Principles and fundamentals can be similar, but specific requirements often vary. In view of this, we will talk about different types of pipe individually. Long term behaviors of PVC, CPVC, PP, and HDPE are illustrated in Figures 7.1, 7.2, 7.3, 7.4, and 7.5.

PVC PIPE

Sewers are often made of PVC pipe. The diameter of the pipe can range from small to large. How the PVC pipe for sewers is handled and installed is essential to a successful installation. Some characteristics of PVC sewer pipe make it subject to damage that might not affect another type of pipe. For example, PVC pipe used in sewers can become brittle in cold weather. Dropping cold PVC pipe on a hard surface can crack the pipe. While the crack may not be very visible, it will cause a leak. Water can create extreme problems when joining the pipe with fittings. Any water in the joint can create a void that will leak. Mud is also a problem when joining PVC pipe and fittings.

A good installation begins in the field with the handling and storage of pipe and fittings. Any incoming pipe should be checked for visual defects upon delivery. Unloading the pipe, whether by hand or machine, should be done in a manner that will not damage the pipe. Sliding cold PVC off a truck and allowing it to drop onto a concrete floor is not the right way to unload a truck. The pipe should

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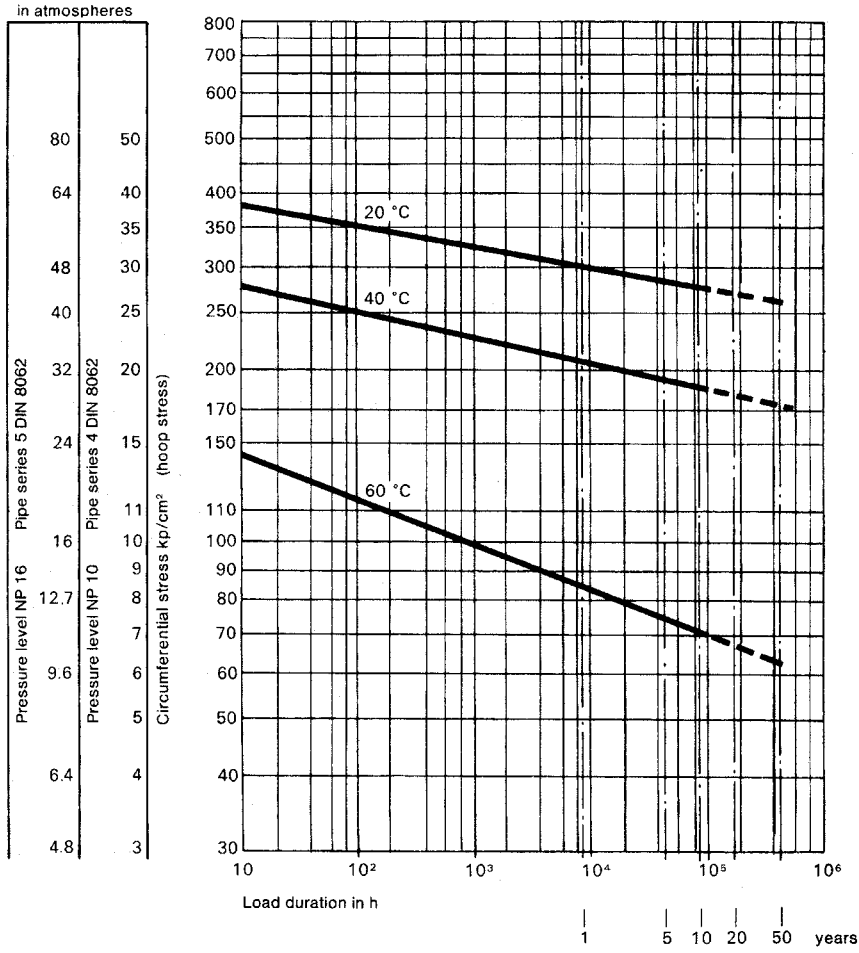

FIGURE 7.1 Long-term behavior of PVC. *(Courtesy George Fischer Engineering Handbook)*

never be dropped. While PVC pipe is resilient, it can crack, even in warm weather, if it is mishandled.

It is best to store PVC pipe in a protected location. Keeping the pipe dry is extremely advantageous. If the pipe is not contained by bindings or containers, it should be blocked to avoid a rollout collapse of the pipe. Never stack the pipe so high as to create a safety risk.

When a bell-type pipe is used, the bell should be laid out by the trench with the bell ends pointing in the direction that work will progress. If the ground surface is wet or muddy, the pipe should be laid out on a waterproof groundcover, such as a tarp. Keep the pipe and fittings dry and clean.

All trenches should be created with safety in mind. Deep trenches should be fitted with appropriate protection for workers. It is also important to keep the trench

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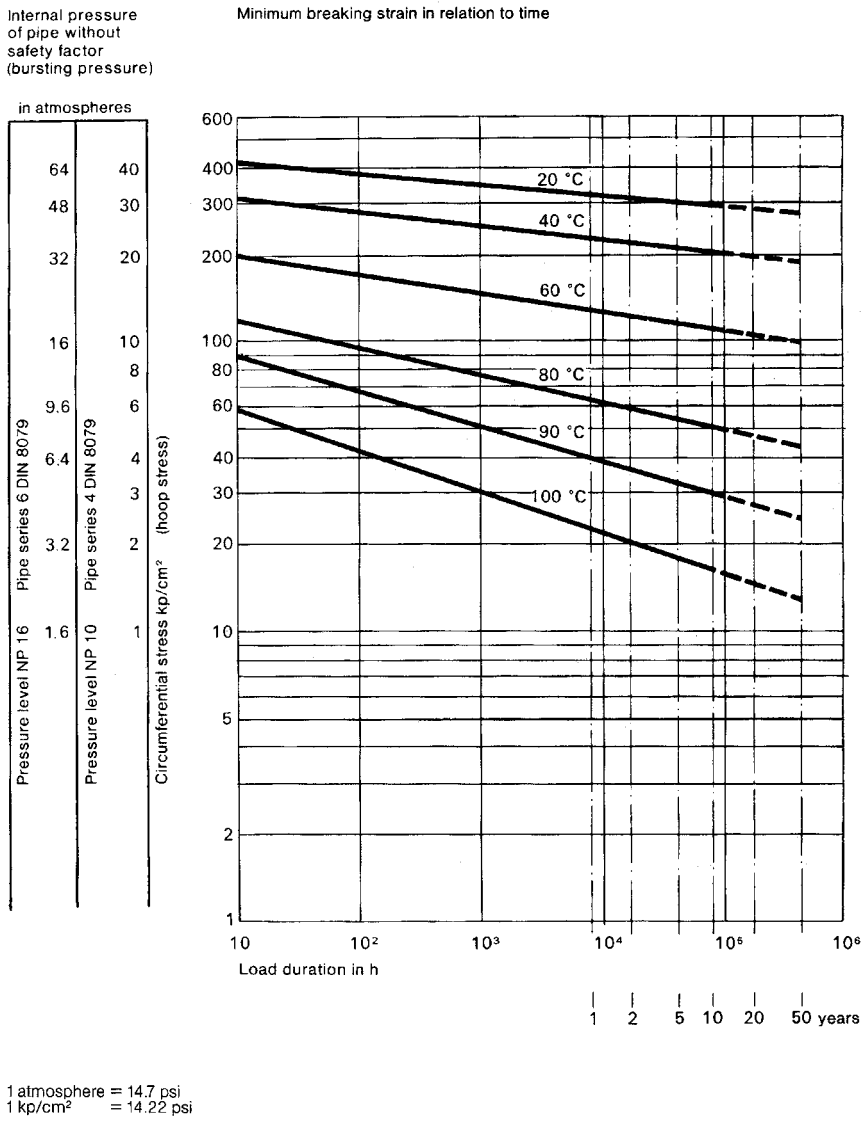
PIPE HANDLING AND CONSTRUCTION



1 atmosphere = 14.7 psi
1 kp/cm² = 14.22 psi

FIGURE 7.2 Long-term behavior of CPVC. *(Courtesy George Fischer Engineering Handbook)*

bed as dry and firm as possible. Once installed, PVC pipe can float if a trench is subjected to a collection of water. This problem can be solved with backfilling. As a rule-of-thumb, cover the pipe with backfill material so that the backfill height is at least 1.5 times the size of the pipe diameter. As an example, a 4-inch pipe would require at least 6 inches of backfill to prevent floatation from flooding.

PVC is fairly easy to cut. The methods used to cut the pipe vary with installers and pipe size. Pipe with a small diameter is sometimes cut with roller-type cut-

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PIPE HANDLING AND CONSTRUCTION

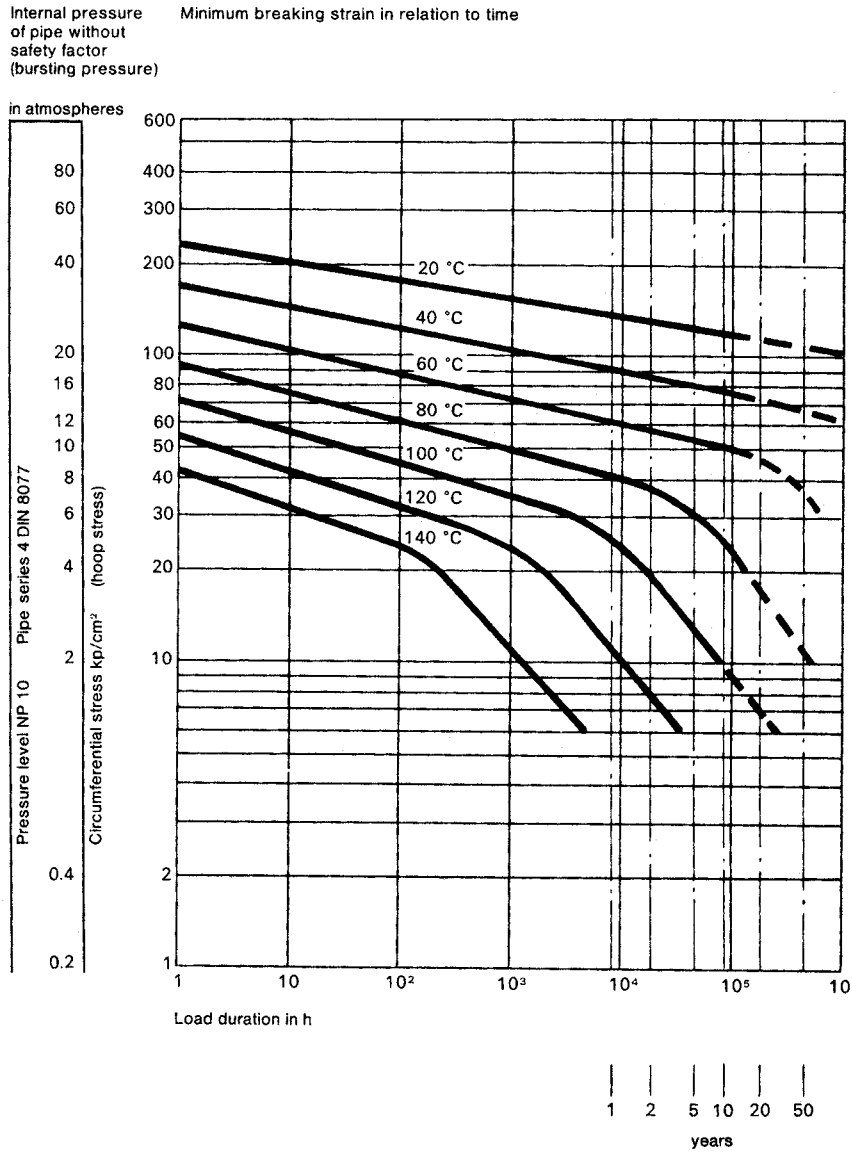

FIGURE 7.3 Long-term behavior of PP. *(Courtesy of George Fischer Engineering Handbook)*

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PIPE HANDLING AND CONSTRUCTION

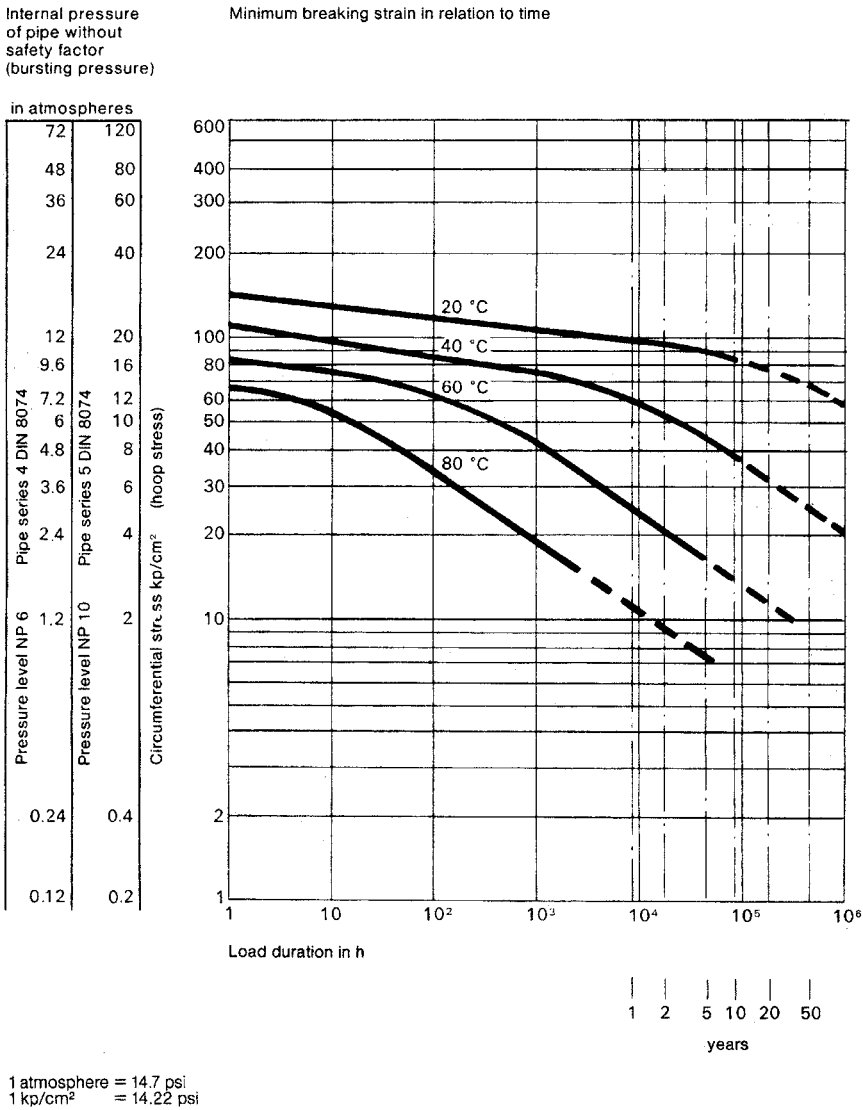

FIGURE 7.4 Long-term behavior of HDPE. *(Courtesy of George Fischer Engineering Handbook)*

ters, similar to the type used to cut copper or steel pipe. Handsaws, chop saws, and other types of electric saws can be used. The key is to cut the pipe end squarely. There will be burrs on the end of the pipe. These burrs should be removed and the pipe end should be beveled. This can be done with a beveling tool, a wood rasp, or even a power sander. Eye protection should be worn to protect workers cutting pipe or in the area where pipe is being cut. Working conditions for PVC fittings are illustrated in Figure 7.6.

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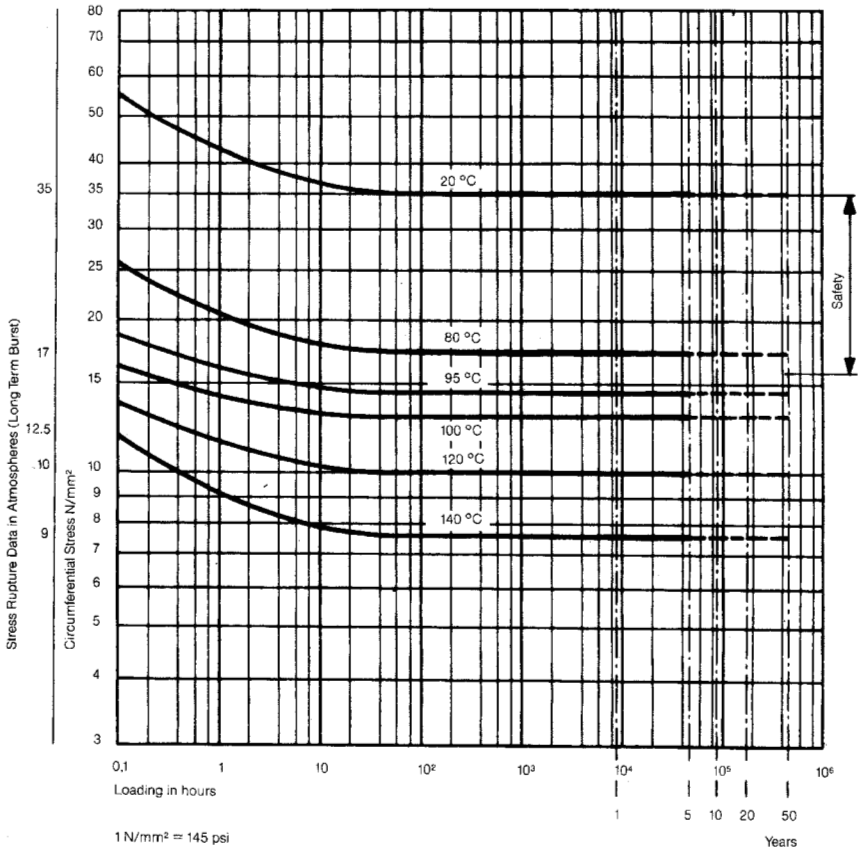

FIGURE 7.5 Long-term behavior of SYGEF. *(Courtesy of George Fischer Engineering Handbook.)*

SOLVENT-WELDED JOINTS

Solvent-welded joints are common when working with small-diameter sewers. The joining process for this type of pipe and fittings is simple. The surface of the pipe ends and the inner fitting hubs should be dry, clean, and free of any debris. A primer is first applied to the pipe ends and the fitting hubs. Then a solvent-weld material, normally called glue by workers in the field, is applied to the pipe ends and fitting hubs. The pipe end is inserted into the fitting and turned to assure full coverage of the bonding material. While these joints are fairly secure at this point, they should not be exposed to water, impact, or extreme movement. It can take several hours, depending upon climatic conditions, for a solvent-weld joint to dry to a satisfactory condition. Testing for leaks should not be done immediately. Wait until you are sure the joints have had time to cure properly before testing. Thermal application range of sealing materials is illustrated in Figure 7.7.

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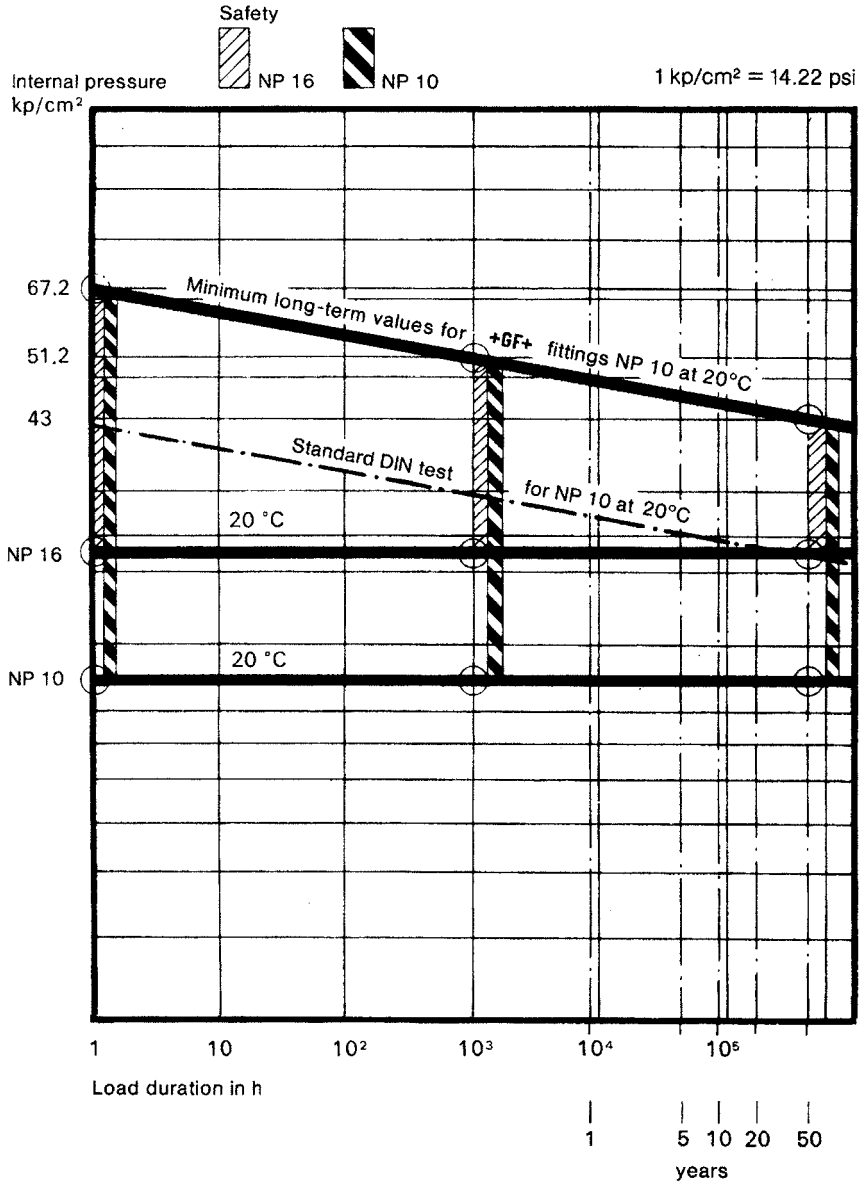

FIGURE 7.6 Working conditions for PVC fittings. *(Courtesy George Fischer Engineering Handbook)*

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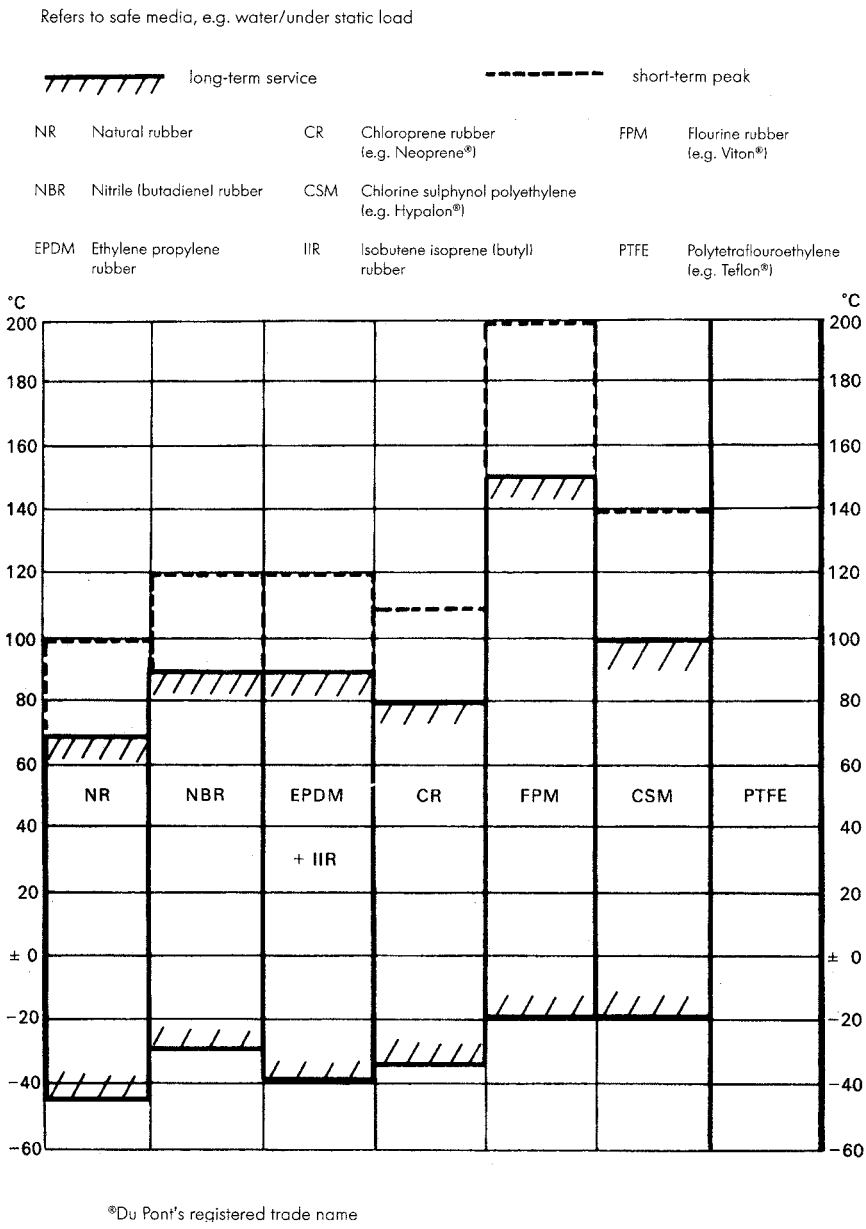

FIGURE 7.7 Thermal application range of sealing materials. *(Courtesy George Fischer Engineering Handbook)*

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PIPE HANDLING AND CONSTRUCTION

GASKET JOINTS

Some types of PVC pipe are connected with gasket joints. This requires a different type of installation procedure. Sometimes the gaskets are supplied separately from the pipe. In other cases, the gaskets are provided as a part of the pipe. When installing gaskets that were not shipped as a part of the pipe being installed, be sure that the gaskets are clean and dry before using them. Both the gasket groove and the spigot should be clean and dry prior to connection. Pipe that is shipped with gaskets in place will require installers to merely make sure that the gaskets are clean. The gaskets should not be removed for cleaning.

A manufacturer recommended lubricant is needed to make a connection with gasket-type pipe. The lubricant is applied to the bevel of the spigot end of pipe. This lubricant is applied from the end of the pipe to a point about halfway to the insertion line. You should not place any lubricant in the bell end of the pipe.

The next step is to insert the spigot end of the pipe into the bell end. This can be a tricky task to perfect in some cases. Large-diameter pipe requires the use of various types of mechanical devices to create a joint. Smaller pipe can be joined by hand. A good joint is made when the insertion line of the spigot end of a pipe is lined up with the edge of the bell that the spigot is being inserted into.

If there seems to be a problem with making a connection, you should check the gasket material to see if it is in good condition. Any gasket that appears to be defective or damaged should be replaced. When the gasket seems okay, seat the gasket in the bell properly and attempt the joining process again.

When mechanical assistance is required to create a joint, there are a few additional considerations to keep in mind. Installers must be sure that the spigot end of a pipe is not inserted too far into the bell end of a pipe. There is some risk of existing joints being damaged if too much force is used to join pipe sections. Many problems can arise if excessive force is used to create a joint. Gaskets can roll up and cause a poor connection. The pipe bell might split. A pipeline might not pass an air test if excessive force is used to create joints.

One common means of mechanical assistance is very simple. All it involves is the use of a wooden block and a lever, that is also frequently made of wood. A typical 2-×-4 wall stud can be used to build such a device. A short piece of the lumber is attached to the lever. Once a section of pipe is aligned for insertion, the block of wood on the lever is placed against the pipe end with the lever at a backward angle. The lever is then pushed forward. This motion provides the power needed to insert a pipe end into a bell.

TRENCH INSTALLATION

A trench installation with PVC pipe calls for several levels of fill material in a trench. The first is the bedding. Bedding is usually less than 6 inches thick and is used to provide continuous support of the pipe. The next layer of fill is the haunching that

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comes from the top of the bedding to a point about half way up the pipe diameter. Then there is initial backfill and finally there is the final backfill.

Bedding is crucial since it supports the underside of a pipe. Haunching is also important. It is a major factor in controlling pipe performance and deflection. This also provides pipe support. Compaction is needed to assure proper pipe placement and support. Initial backfill material must be free of rocks and other objects that might damage a pipe when the backfill is placed in a trench. Generally, initial backfill should be at least 6 inches in depth. This layer of backfill serves as protection for the pipe when other backfill material is installed. Final backfill should be free of large rocks, frozen ground, rubble and other items that might cause voids or sinking in the backfill layer over a period of time.

POLYETHYLENE PIPE

Polyethylene (PE) pipe is flexible. Several types of pipe can be considered flexible and all of them need to be protected from deflection. When installed below ground, flexible pipe support is a major requirement of trench bedding and backfilling. Above-ground installations require adequate support in the form of hangers or clamps. As with any piping material, PE pipe should be handled and stored in a way that will not damage the pipe. PE pipe should never be placed in contact with sharp objects.

Deflection is an increase or decrease in pipe diameter. Kinking of the pipe and crushing of the pipe must be avoided. Where there is an increase in diameter the condition is called a rise. Squeezing the pipe causes a decrease in diameter. When buried, the embedment materials surrounding PE pipe must be planned carefully.

Buried PE pipe depends on a trench bed to maintain adequate support. The in-situ soil, also known as the native soil, of the trench is not as important as the backfill material used under, around, and over the pipe. A designer must factor in all soil conditions when specifying embedment materials. The categories of embedment material for PE pipe is the same as those discussed for PVC pipe. Some considerations for backfill material include how the material will stand up to the final installation, the ease of placement and compaction, and the cost and availability of the material.

Class l and class ll soils are considered good materials for use in trenches with PE pipe. Both classes of material are granular and provide excellent pipe support. A class l material is a manufactured aggregate and is most often crushed stone. The class ll material is more of a sandy material. The two types of embedment materials can be combined and they allow for good drainage. It is important to keep the backfill material within acceptable ranges for the size of the pipe being supported. For example, a 4-inch pipe should have an embedment material surrounding it that is no more than one-half an inch in size. Pipe with a diameter of 18 inches or more should be surrounded by fill material that is not more than 1.5 inches in size.

The use of cement-stabilized sand is sometimes called for as an embedment material. This is a mixture of cement and sand. Normally, the cement content is

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about 3 to 5 percent of the sand volume. The mixture is placed with compaction rather than in a pouring fashion. Moisture is added to the mix before placement and compaction is done. When allowed to cure overnight, a cement-stabilized sand mixture installed before backfilling can reduce pipe deflection.

Class lll material and class lVa material do not provide the stiffness that a class l or class ll material can. This is due to increased clay content. Very little pipe support is offered by either class lVb and class V materials. It's not unusual for pipe to float when installed with such materials.

Compaction is a factor in most buried-pipe installations. The compaction is sometimes done with hand-held, manual tampers. Gasoline-powered tamping machines are often used. Other forms of power compactors can be used. In all cases, the compactors must be employed in a way that does not have a negative impact on the pipe being installed. Above-ground installation instructions were given in Chapter 5. Therefore, we will now move into the discussion of joining PE pipe.

PIPE-JOINING PROCEDURES

Pipe-joining procedures for PE pipe are different than the joining methods used for PVC pipe. This type of joining is done with either heat fusion or mechanical fittings. Plastic pipe may be joined to other types of material with the use of compression fittings, flanges, or other qualified types of transition fittings. The type of joint used is up to designers and installers, but it can be subject to the application. Let's start with heat fusion.

Heat fusion offers 3 types of joints. They are butt joints, saddle joints, and socket fusion. There are two spinoff joints for producing socket- and saddle-heat-fusion joints. The concept of a heat-fusion joint is simple. You heat two surfaces to a specific temperature and them fuse them together with an application of sufficient force. Done correctly, the two materials mix together and form a joint. This type of joint can be as strong as the pipe being joined. When a fused joint cools to near ambient temperature the joint can be handled and worked with.

There are basically two ways to create fused joints. The first type uses heating tools to heat the materials to be joined. A second type uses electric current to make an electrofusion joint. This is done for socket joints and saddle-type joints.

Butt fusion is one of the most common ways for connecting sections of large-diameter PE pipe. There are only 6 steps in this process. A butt-fused joint is inexpensive, permanent, and does not restrict flow in the pipe. Making butt-fusion joints in the field is not difficult when the proper equipment is available to work with. The joining equipment is available for pipe with a diameter of up to 72 inches. What are the six steps required? First, an installer must securely fasten the components that are to be fused together. Then they have to face the pipe ends. The pipe profile must be aligned properly. Melting the pipe interfaces is next. Both profiles are joined together and then held under pressure. Sounds simple, but there is more to know about this process.

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Securing the pipe requires that the pipe will not move during the joining process. The facing process must put the pipe ends in a parallel mating surface. A rotating planer block design is normally installed in equipment that is used for facing. There has to be a perfectly square face that is perpendicular to the pipe centerline on each pipe end. It is unacceptable for any detectable gap between pipe ends to exist.

Alignment of the pipe ends is essential. This is usually done by adjusting the joining equipment. Then the ends of the pipe sections are heated. The temperature is determined by the manufacturer's recommendations. During the heating process, the pipe must maintain interface pressure and the time for making the joint must be monitored and meet the manufacturer's recommendations. A molten bubble or bead will be visible when this procedure in done correctly. The joining machine being used should monitor temperature ratings. Due to local conditions, the thermometer ratings can be fooled. To compensate for this risk, a pyrometer should be used periodically to keep track of temperature requirements. If any molten plastic residue is present on the heater face, it must be cleaned to ensure good fusion joints.

After the heating application reaches the proper temperature, the heating device is removed and the pipe ends are put together to form the fusion joint. Consult manufacturer recommendations for interface pressure and the bead size of molten material required to make a solid joint.

Once a molten joint is formed it must be held in place so that it can cool and create a satisfactory joint. Consult manufacturer recommendations for cooling times. If joint beads need to be removed, there is equipment available for such a process.

Installing a saddle with sidewall fusion is not uncommon. This process requires the use of a saddle-fusion machine. The process can be done without a machine, but it is generally not recommended. Since this process is generally discouraged, it will not be discussed here.

There are eight steps involved in making a saddle-fusion joint. The first step is to clean the pipe where a joint will be made. Once this is done, install a saddle-adapter heater of the proper size. Make sure that the saddle is in direct and tight contact with the pipe. However, do no overtighten. Bring the heater up to a temperature recommended by the manufacturer. The next step is to install the saddle-fusion machine. Again, be careful not to tighten the device to a point of collapsing the pipe.

You are now ready to clean the joint area again. It is highly recommended that you rough up the joint surfaces with utility cloth. The cloth should have a grit rating of 50 or 60. Don't use sandpaper or other material that may leave grit or other unwanted deposits on the joint surfaces.

Check to be certain that the proper saddle-fitting holding inserts are in the fusion machine. Place the fitting on the pipe and place the fitting into the insert. Slight downward force is then applied on the fitting. Make sure that there is a good fit between the pipe and fitting. Double check the fit between the fitting and pipe.

Heater temperature should be monitored periodically. Follow manufacturer recommendations when heating the pipe and fitting. Once the materials to be fused

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are up to temperature, remove the heater and quickly inspect the melt pattern on the pipe and fitting. Then proceed to join the pipe and fitting with proper fusion force. Maintain a stable fit on the joint until it has cooled to ambient temperature.

There are only 5 steps in socket fusion. The proper equipment for the job must be selected. Pipe ends are squared and prepared and then the portions to be fused are heated. The parts are joined and then allowed to cool to ambient temperature.

Electrofusion

Electrofusion is another way to join plastic pipe with a fused joint. The main difference between electrofusion and regular fusion joining is the process of heating the materials. An electrofusion joint is made by heating internally rather than externally. This can be done with either a wire coil at the interface of the joint or by the use of a conductive polymer. Electrical current creates the heat needed to fuse a joint.

When fused joints are not wanted, you can turn to a wide variety of mechanical connections to join PE pipe and fittings. Mechanical compression fittings are commonly used on PE pipe that has a diameter of 2 inches, or less. A bolt-type mechanical coupling can be used to join the ends of PE pipe. This same device can be used to join PE pipe with steel pipe. Comparisons of the strength characteristics of metal and plastics are illustrated in Figure 7.8. Stab-type mechanical fittings are another option. It is safe to say that there is no shortage of options when it comes to joining PE pipe and fittings.

CPVC PLASTIC PIPE

CPVC plastic pipe is approved for use with both hot and cold water. Small sizes of CPVC pipe, up to 2 inches in diameter, are joined with solvent cement. Larger CPVC pipe is schedule 80 pipe and is threaded to iron pipe size outside diameters. The joining process for solvent-weld connections is very similar to the process used to join PVC pipe.

Several types of transition fittings are available for connecting CPVC pipe to other types of materials. There are unions, compression fittings, and metal fittings with CPVC socket connections on one end. One of the most commonly used transition fittings is a CPVC male or female adapter that is screwed into or onto the different type of material. There are, however, two potential problems when using straight CPVC threaded adapters. If the adapter is subjected to a wide temperature range a drip leak may occur. It is also possible for some thread sealants to chemically attack the composition of the CPVC. The simple solution is to use metal threaded fittings that provide a socket for a solvent-welded joint on one end.

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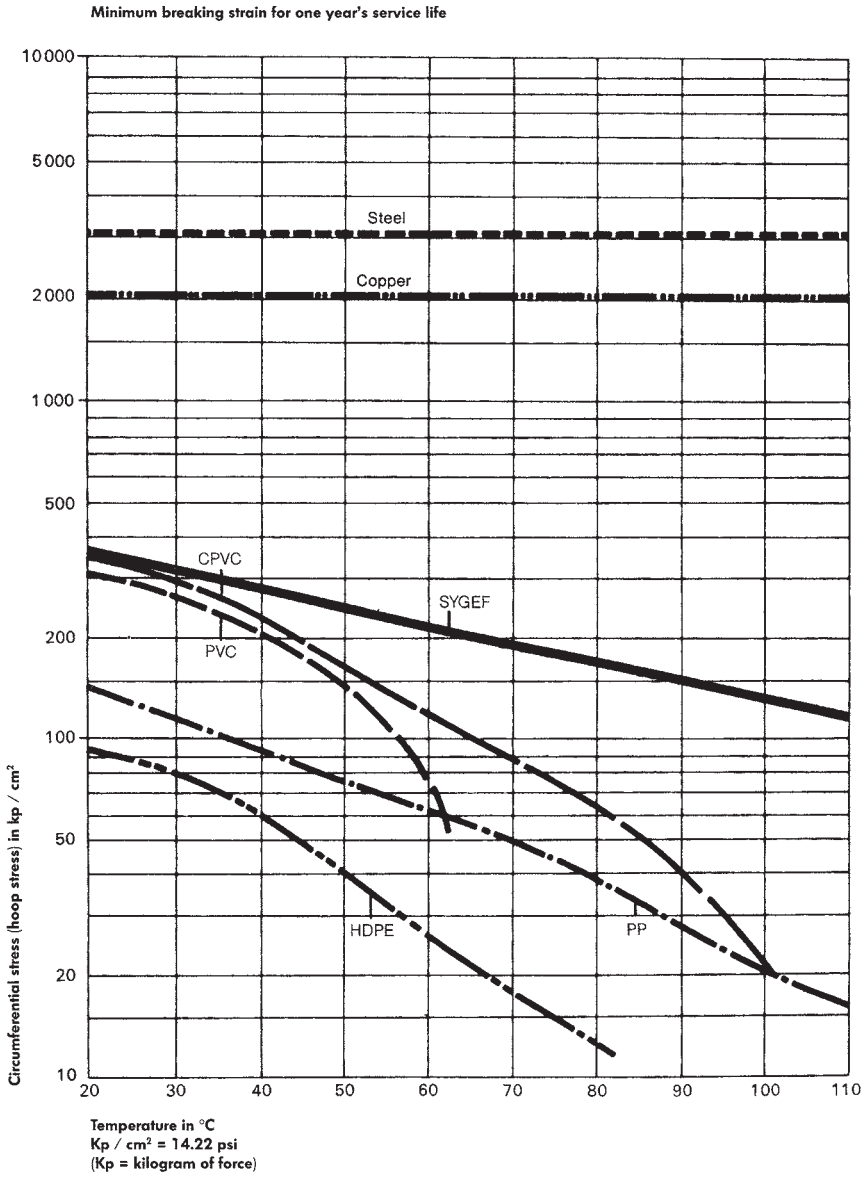

FIGURE 7.8 Comparison of the strength characteristics of metal and plastics from 20 degrees C. to 110 degrees C. *(Courtesy George Fischer Engineering Handbook)*

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OTHER TYPES

There are other types of plastic pipe in use for various purposes. PEX pipe has become very popular for water distribution and for in-floor radiant heating. This pipe, or tubing as it may be called, comes in rolls and is easy to cut and install. ABS pipe has seen extensive use as a drainage and vent pipe, but PVC pipe has overshadowed it in recent years. Corrugated pipe is used in nonpressure applications, such as sewers, culverts, and subdrainage systems.

Regardless of the type of pipe you are working with, you should refer to manufacturer's recommendations and follow them. There are many general principles that can be applied to installation methods, but there is no substitute for specific instructions provided by manufacturers and appropriate building, gas, and plumbing codes.

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CHAPTER 8
HORIZONTAL DIRECTIONAL DRILLING

Horizontal Directional Drilling (HDD) is probably the fastest growing technology in the trenchless industry. HDD has gained widespread acceptance in the construction industry over the past decade. Horizontal directional drilling in North America has grown from 12 operational units in 1984 to more than 2000 units operating in 1995. The reason for the popularity is that HDD represents a significant improvement over the traditional open-cut and cover methods for installing pipelines beneath obstacles.

Equipment and installation techniques used in the HDD process are an outgrowth of the technologies from the oil field and water well industries. There is a wide range of directional boring units in use today, from mini drilling rigs, which are used for small pipes and conduits to maxi rigs, which are capable of installing large diameter pipelines. The maximum length of a HDD is determined by many parameters including rig size, soil conditions and pipe diameter. Installations as long as 6000 feet have been successfully completed. Current HDD equipment can operate in a wide range of soil conditions, from extremely soft soils to full-face rock formations with unconfined compressive strengths of 40,000 psi.

ADVANTAGES OF HDD

Traditional open trenching methods for installing pipe can be expensive, particularly in congested urban areas. Construction involves digging around existing utilities to get to the required depth, which slows down the operation. Also, not only must the trench be backfilled, often sidewalks, pavement, brick paving, sod, or other surfaces must be replaced. In addition, open cut operations often cause interruption of traffic and disruption of near by commercial activities. Excavation requirements

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in HDD are minimal. As a result, in crowded urban areas, HDD is increasingly viewed as the preferred technology. It minimizes the negative impact on residents and businesses, and eliminates the need for the removal and restoration of expensive landscaping. In open areas, HDD provides an efficient method for crossing obstacles such as rivers, highways, rail tracks, or airfield runways. The HDD method also eliminates the cost and time associated with installing de-watering facilities for operations carried out below the ground water table level.

Applications

The market for horizontal directional drilling is experiencing a continuous growth worldwide. The installation of pipe and utility conduits in urban areas and across rivers and highways is the mainstay of the horizontal directional drilling industry. It is common practice to use HDD for the installation of new networks of power, natural gas, and telecommunications.

Municipal applications are perhaps the most promising future market for horizontal directional drilling. Recent advancements in equipment and tracking systems make the use of HDD cost efficient for projects that involve larger diameter products and stricter placement tolerances, as it is the case in many municipal applications. As an increasing number of municipal engineers become aware of the technology and its advantages, this market is expected to grow rapidly over the next five years. The oil, gas, and petrol-chemical industries are another important market for the directional drilling industry.

HDD PROCESS

Installation of a pipe by HDD is usually accomplished in two stages. The first stage involves directionally drilling a small diameter pilot hole along a designed directional path. The second stage consists of enlarging (reaming) the pilot hole to a diameter that will support the pipeline and pulling the pipeline back into the enlarged hole. A HDD drill rig is used to drill and ream the pilot hole and pull the pipeline back through the hole. HDD drill rigs provide torque, thrust, and pullback to the drill string. The drill drive assembly resides on a carriage that travels under hydraulic power along the frame of the drill rig. The thrust mechanism for the carriage can be a cable, chain, screw, or a rack and pinion system. Table 8.1 lists the three general categories of drilling rigs used in the industry.

Mini Rigs are mounted on a trailer, truck, or a self-propelled track vehicle. These systems are designed for drilling in relatively soft semi-consolidated formations and are used primarily for installation of utility conduits and small diameter pipelines in congested urban areas. They are not suitable for drilling gravel, cobble, or other formations where borehole stability is difficult to maintain.

Medium drilling rigs are used to install larger conduits and pipelines, normally up to 12 inches in diameter, with drill lengths ranging up to 1900 feet. They are particularly suitable for the installation of municipal pipelines, as they are sufficiently

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TABLE 8.1 Typical Characteristics of HDD Rigs

	Mini Rigs	Midi Rigs	Maxi Rigs
Thrust/Pullback	<20,000 lbs.	20,000–80,000 lbs.	>80,000 lbs.
Maximum Torque	<2000 ft.lbs.	2000–20,000 ft.lbs.	>20,000 ft. lbs.
Drilling Speed	>130 RPM	130–200 RPM	<200 RPM
Carriage Speed	>100 ft/min.	90–100 ft./min.	<90 ft./min.
Carriage Drive	Cable or Chain	Chain or Rack & Pinion	Rack & Pinion
Drill Pipe Length	5-10 ft.	10–30 ft.	30–40 ft.
Drilling Distance	<700 ft.	700–2000 ft.	>2000 ft.
Power Source	<150 HP	150–250 HP	>250 HP

compact to be used in urban areas, while at the same time have the capacity of installing large diameter products beneath highways, subdivisions, and rivers. Bores can be installed in unconsolidated to consolidated sediments.

Maxi rigs typically involve a large operation with multiple trailer-mount support equipment and substantial mobilization and demobilization periods. High operating costs make their use somewhat prohibitive in the utility installation market, and they are employed primarily in the pipeline industry. These large units may be used in the installation of large diameter pipes (24-48 inches) and or exceptionally long bores.

In addition to the drilling rig, a variety of support equipment may be required. Depending on the HDD project, a drilling fluid or mud cleaning and recirculation unit, drill pipe trailer, water truck, and pump and hoses may be required. An excavator is needed to dig the entry, exit, and recirculation pits. In urban or environmentally sensitive areas a vacuum truck may be required to handle the fluid in the return pits or inadvertent returns.

Bore Installation

The bore is launched from the surface and the pilot bore proceeds downward at an angle until the necessary depth is reached. A small diameter drill string penetrates the ground at a prescribed entry point and the design entry angle, normally between 8-12 degrees. At a prescribed depth or point the drill pipe is bent to follow the proposed drill path and the designed bending radius. Then the path of the bore is gradually brought to the horizontal, followed by another bend before the bore head is steered to the designated exit point where it is brought to the surface. Choosing the proper drill pipe is a key element in the HDD process. The outer diameter and the wall thickness of the drill pipe have limitations that influence the bend radius of the bore. Larger diameter drill pipe cannot bend in short distances and cannot be used on short bores. Smaller drill pipes are more flexible and suited for short bores in the right soil conditions.

During the drilling process the bore path is traced by interpretation of electronic signals sent by a monitoring device, located near the head of the drilling

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string. At any stage along the drilling path the operator receives information regarding the position, depth, and orientation of the drilling tool, allowing him to navigate the drill head to its target. After the pilot string breaks the surface at the exit location, the bit is removed from the drill string and replaced with a back-reamer.

The pilot hole is then back-reamed, enlarging the hole to the desired diameter while simultaneously pulling back the line product behind the reamer.

This is typically referred to as a "continuous" borehole. In some situations with small diameter product pipe or conduit, the pipe can be pulled straight into the pilot hole after the drill is completed. However, in most HDD operations the borehole has to be reamed to enlarge the hole to accommodate pulling in the product pipe. Generally the borehole is reamed to 1.5 times the outside diameter of the product pipe. The purpose of this is to provide an annular void between the product pipe and the drillhole for the drilling fluids and spoils and for the bending radius of the product pipe.

Sometimes it is necessary to ream the borehole without pulling back the pipe. After the drillhole is reamed the product pipe or conduit is pulled back through the reamed hole filled with the drilling fluids. It is best to fabricate the product pipe on the exit side in one section so it can be tested and pulled in one continuous pullback. The drill pipe is connected to the product pipe or conduit using a pullhead or swivel. The swivel is used to prevent rotational torque from spinning the product pipe. A reamer is placed between the pullhead and the drill string to keep the drillhole open.

Drilling and Steering

Drilling curved and horizontal boreholes requires specialized drilling equipment. This equipment is contained in a bottom hole assembly (BHA) that consists of a drilling tool, a bent sub-assembly, and a steering/tracking tool. Pilot hole directional control is achieved by using a non-rotating drill string with an asymmetrical leading edge. The asymmetry of the leading edge results in a steering bias. When a change of direction is required, the drill string is rotated so that the direction of the bias is the same as the desired change of direction. The drill string may also be continuously rotated when directional control is not required. Normally, the leading edge will have an angular offset created by a bent sub or bent motor housing. The most common types of down-hole drilling/steering tools used in the HDD industry are compaction tools and down-hole mud motors.

Compaction heads consists of a wedge shaped drilling bit, which is used for cutting and displacing the soil as well as for steering. To bore a straight hole the drill string is rotated and pushed simultaneously. When a correction in direction is required, rotation stops and the drilling head is preferentially oriented in the borehole. Then the drill rig pushes the entire drill string forward. As the slant on the face of the wedge is pushed against the soil, the entire assembly is deflected in the desired direction. After the steering correction is completed, rotation is resumed until another correction is needed. Compaction type drilling tools are most often used

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in mini and midi size drill rigs to drill through soft to medium consolidated soils, as well as loose and dense sands. When gravel or hard clay is encountered, compaction heads tend to wear rapidly. They are not suitable for drilling in rock formations.

When drilling with compaction heads, steering difficulties are often encountered when trying to drill in very soft soils. This is caused when the resistance to the deflector plate is not sufficient to offset the tendency of the drill string to drop vertically under its own weight. To solve this problem use a larger deflector plate. Steering can be improved by increasing the flexibility at the head of the drill string. A common method is to add a length of smaller diameter more flexible drill rod behind the drill bit.

Mud (down hole) motors are used in ground conditions ranging from hard soil to rock. Mud motors convert hydraulic energy from the drilling mud being pumped from the surface to mechanical energy at the drill bit. This allows for the bit to rotate without drill string rotation. Positive displacement motors are typically used in HDD operations. These motors generate torque and rotation at the drill bit from the flow output of the mud pump. Directional control is obtained by a small bend in the drill string just behind the cutting head. As with the compaction heads, once the correction is made, the complete drill string is rotated to continue boring straight in the new direction. This method costs more than compaction heads and is less common in the utility installation industry.

The advantage of mud motors is that cutting of the formation is done by the mud motor, reducing the drill string rotation requirements, thus making it possible to drill long boreholes to substantial depths. The main disadvantage to mud motors is that they are more expensive in comparison to compaction heads and require hundreds of gallons of drilling fluids per minute.

Tracking

In HDD applications tracking is the ability to locate the position, depth, and orientation of the drilling head during the drilling process. The ability to accurately track the drill is essential to the completion of a successful bore. The drill path is tracked by taking periodic readings of the inclination and azimuth of the leading edge of the drill string. Readings are recorded with a probe that is inserted in the drill collar as close as possible to the drill bit. The three most common type of tracking tools are:

1. Electronic beacon systems (walkover)
2. Combination magnetometer-accelerometer systems
3. Inertial navigation systems

A "walkover system" consists of a transmitter, receiver, and a remote monitor. A battery-powered transmitter is located in the bottom hole assembly near the front of the drill string and emits a continuous magnetic signal. The receiver is a portable, hand held unit, which measures the strength of the signal sent by the

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transmitter. This information is used to determine the drill heads position, depth, and orientation. The remote monitor is a display unit installed at the drilling rig in front of the operator. It receives and displays the information provided by the receiver. This information is used to navigate the drilling head below the surface. The data is recorded to provide the as-built profile of the bore path.

When access to a location directly above the borehole alignment is not possible, or when the depth of the bore exceeds 100 feet, other types of navigation systems should be used. Two systems commonly employed are the magnetometer-accelerometer system and the inertial navigation system. The magnetometer-accelerometer system uses three magnetometers to measure the position (azimuth) of the tool in the earth's magnetic field and three accelerometers to measure the position (inclination) of the tool in the earth's gravitational field. The steering tool sends information via a wire line to a computer at the surface where the azimuth, inclination, and tool face orientation are calculated. As far as operating depth and distance from the drilling rig, this steering tool does not impose any limitation on the rig's operating range. Disadvantages of this system include susceptibility to magnetic inferences from buried metal objects and power lines. Some magnetic-accelerometer systems use a secondary survey system to account for local magnetic influences on the downhole probe. The secondary survey system induces a known magnetic field at the ground surface through a copper wire surface grid. A computer program connected to both the surface magnetic field and the steering tool compares the magnetic field measured by the steering tool and the theoretical magnetic field induced by the system, and compensate for local magnetic interference.

The inertial navigation system uses a system of three gyroscopes and three accelerometers to measure the azimuth and the inclination of the steering tool, respectively. The gyroscopes are aligned to true north at the ground surface before the survey is made. Any deviation from true north during the survey is detected by the gyroscopes and relayed to the surface where the azimuth, inclination, and drilling tool orientation are calculated by a computer. Because of the cost and sensitivity of these systems they are used mainly for calibration purposes.

Drilling Fluids

Drilling fluids are commonly called drilling mud or slurry. Drilling mud is mixed on the surface and pumped down the drill string. The mud comes out at the drill bit and is either left in the annulus of the borehole or circulated back to the surface. Drilling mud is a mixture of water, premium bentonite, and if needed, small amounts of polymer. Bentonite is a non-hazardous material.

Drilling fluids have many uses or functions. The main purposes of HDD drilling fluids are:

- To establish and maintain the borehole integrity
- To transport drill cuttings to the surface by suspending and carrying them in the fluid stream that flows in the annulus between the wellbore and the drill rod.

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- To clean the build-up on the drill bits or reamer cutters by directing high-velocity fluid streams at the cutters. This also cools the bits and electronic equipment
- To reduce the friction between the drill string and the borehole wall aided by the lubricating properties of the drilling fluid
- To stabilize the borehole, especially in unconsolidated soils, by building a low permeability filter or mud cake lining and exerting a positive hydrostatic pressure against the borehole wall preventing collapse as well as preventing formation fluids from flowing into the borehole or drilling fluids from exiting the borehole into the formation (lost of circulation)
- To provide hydraulic power to downhole mud motors if used

A drilling fluid is composed of a carrier fluid and solids (clay or polymer). The carrier fluid carries the solids down the borehole where they block off the pore spaces on the borehole wall. The blockage is referred to as a filter or mud cake. The ideal mud cake will form quickly during construction of the wellbore and prevent intrusion of drilling fluid into the formation. At times additives such as detergents are added to the drilling fluids to counteract some of the formation characteristics such as swelling and stickiness.

Drilling fluids that are not properly contained on the surface can cause problems. A drilling plan should include the procedures for handling the drilling fluids as they return to the surface. Pre-dug pits and trenches or a vacuum truck should be a part of the bore planning. In addition, a drilling fluid disposal plan is a requirement for the HDD project. After all the federal, state, and local regulations are met, spreading the used bentonite slurry on pastures and fields, or pipeline rights of way with the land owner's permission can benefit the contractor and the land owner.

HDD CONSIDERATIONS

There are several factors to take into account when considering the feasibility of HDD applications.

Feasibility

The design and engineering of a HDD project is affected by actual site conditions including soil formations, terrain, existing utilities, and equipment set-up restraints. The final bore may differ from the original design because of the limitations of downhole tooling and the actual drilling conditions encountered. There are many factors to consider when deciding if HDD is the best installation method for a pipeline or utility conduit. Economics or cost is always a primary factor. In many instances HDD provides the best economical choice and in oth-

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ers it does not. However, determining if the potential HDD application is technically feasible is the key factor. Due to the capabilities of today's HDD tools and drill pipe there are limitations on the length of a bore and the diameter of the product pipe or conduit. The equipment in use today involves thrusting pipe from the surface to drill a pilot hole. There are limitations on the amount of thrust that can be applied to the drill pipe. In addition, control of the drill path diminishes over long lengths.

Subsurface Soil Material

While many factors have an impact on the feasibility of a HDD, the feasibility is primarily limited by the subsurface conditions. Subsurface conditions consisting of large grain content (gravel and cobbles) and excessive rock strength and hardness can prevent a successful HDD application. Coarse-grained soil materials are a serious limitation on the feasibility of a HDD. It is hard for the drilling fluid to fluidize the coarse soil material. Boulders and cluster of cobbles can remain in the drill path and obstruct the drill bit, reamer, or pipeline. Exceptionally strong and hard rock may hamper all phases of a HDD operation. There have been successful HDD operations in rock with unconfined compressive strengths exceeding 12,000 psi and Mohs Scale of Hardness factors above 7. However, these conditions are usually difficult to penetrate, especially at depths. When pushing against hard rock the drill string tends to deflect rather than penetrate. Table 8.2 provides some general guidelines for the feasibility of HDD based on earth material type and gravel percent by weight. Practical experience and engineering judgment must be used applying the guidelines shown in Table 8.2.

Design Factors

Typical pipe products installed by the HDD method include steel, High Density Polyethylene (HDPE), Polyethylene (PE), and Polyvinyl Chloride (PVC) conduits, as well as direct buried cables. During the HDD installation, the pipe product will experience a combination of tensile, bending, and compressive stresses. The magnitude of these stresses is a function of the approach angle, bending radius, product diameter, length of the borehole, and the soil properties at the site.

By properly selecting the radius of curvature and type of product, the design engineer can ensure that these stresses do not exceed the product pipe capacity during the installation. Ideally, the design should call for a minimum number of joints. If joints are necessary, flush joints (butt fusion) are preferable to glued or threaded joints that tend to increase the drag on the product in the borehole. Other considerations include minimum cover, minimum separation from existing utilities, tolerances for deviation in the vertical, and horizontal profiles and maximum true depth.

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TABLE 8.2 HDD Feasibility

Earth Material	Gravel % by Weight	HDD Feasibility
Very soft to hard strength, possibly slickensided clay	NA	Good to Excellent. Penetration of strong clay surrounded by looser soils may result in the bit skipping at the interface. Bit steering may be difficult when passing through soft soil layers.
Very loose to very dense sand with or without gravel traces.	0 to 30	Good to Excellent. Gravel may cause steering problems.
Very loose to very dense gravelly sand	30 to 50	Marginal. In these conditions drilling fluid characteristics are critical to success. Bit steering may be inaccurate.
Very loose to very dense sandy gravel	50 to 85	Questionable. Horizontal penetration for any appreciable distance will be extremely difficult. Bit steering will be inaccurate.
Very loose to very dense gravel	85 to 100	Unacceptable. With current technology horizontal penetration is almost impossible. This type of material must be avoided or penetrated at a steep angle.
Rock	NA	Excellent to Unacceptable. Softer or weathered materials offer good HDD characteristics. Penetrating solid rock after passing through soil may be difficult due to the bit's tendency to skip on the lower hard surface. Rock in the rounded cobble form is almost impossible to drill.

General Guidelines

When considering a HDD project it is usually best to consult with an experienced contractor and a qualified engineer. Here are some general considerations that should be considered:

- Select the HDD path that provides the shortest reasonable distance
- Find routes and sites where the pipeline can be constructed in one continuous length
- Compound bends are possible, but it is best to use as straight a drill path as possible
- Avoid entry and exit elevation differences in excess of 50 feet. Both points should be as close as possible to the same elevation
- Locate buried structures and utilities within 10 feet of the drill-path

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- Observe and avoid aboveground structures, such as power lines, which might limit the height available for construction equipment
- Long crossings with large diameter pipe require a more powerful drill rig
- The larger the pipe diameter, the larger the volume of drilling fluids that must be pumped, requiring larger pumps and mud-cleaning and storage equipment
- Develop as-built drawings based on the final drill path. The as-built drawings are essential to knowing the exact pipeline location and to avoid future third party damage

HDD SITE CHARACTERIZATION

Site Survey

Conducting a site survey is a primary part of the HDD site characterization. The survey should include both surface and subsurface investigations. Based on the information from the site survey, a plan and profile drawing is developed. The drawing is used for contract documents and to make a working profile that will be used for navigation of the bore and developing as-built drawings. See Figure 8.1 for an example of a HDD plan and profile drawing.

Geotechnical Factors

The decision to use the HDD method for a crossing should be based on an understanding of the HDD process and the crossing site's characteristics. The natural and man-made features in the area will dictate the design for the HDD crossing. A vital element of the HDD design process is a comprehensive geotechnical survey to identify soil formations at the potential HDD site. The purpose of the geotechnical investigation is to determine if directional drilling is feasible, and to determine the most efficient way to accomplish it. Using the information gathered from the geotechnical survey, the best crossing route can be determined, drilling tools and procedures selected, and the drill path designed. The extent of the geotechnical investigation depends on several factors such as the pipe diameter, bore length, and the nature of the HDD crossing. During the survey, the geotechnical consultant will identify a number of relevant items including the following:

- Soil identification to locate rock, rock inclusions, gravelly soils, loose deposits, discontinuities and hardpan
- Soil strength and stability characteristics
- Groundwater

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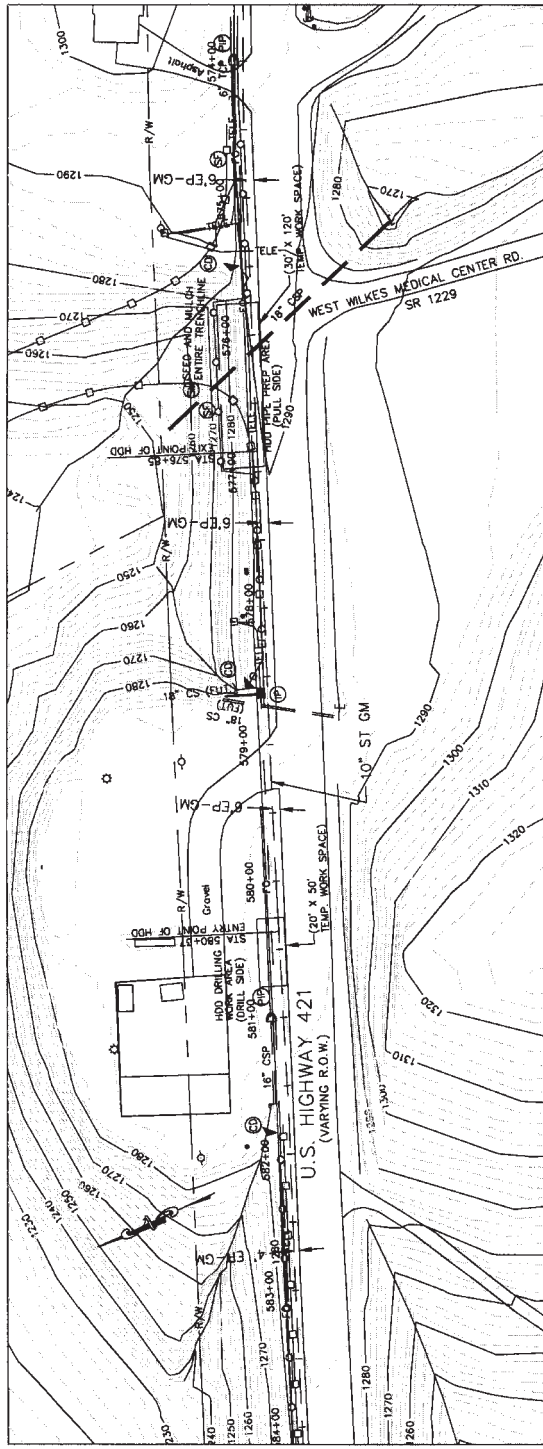

FIGURE 8.1 HDD plan and profile (alignment).

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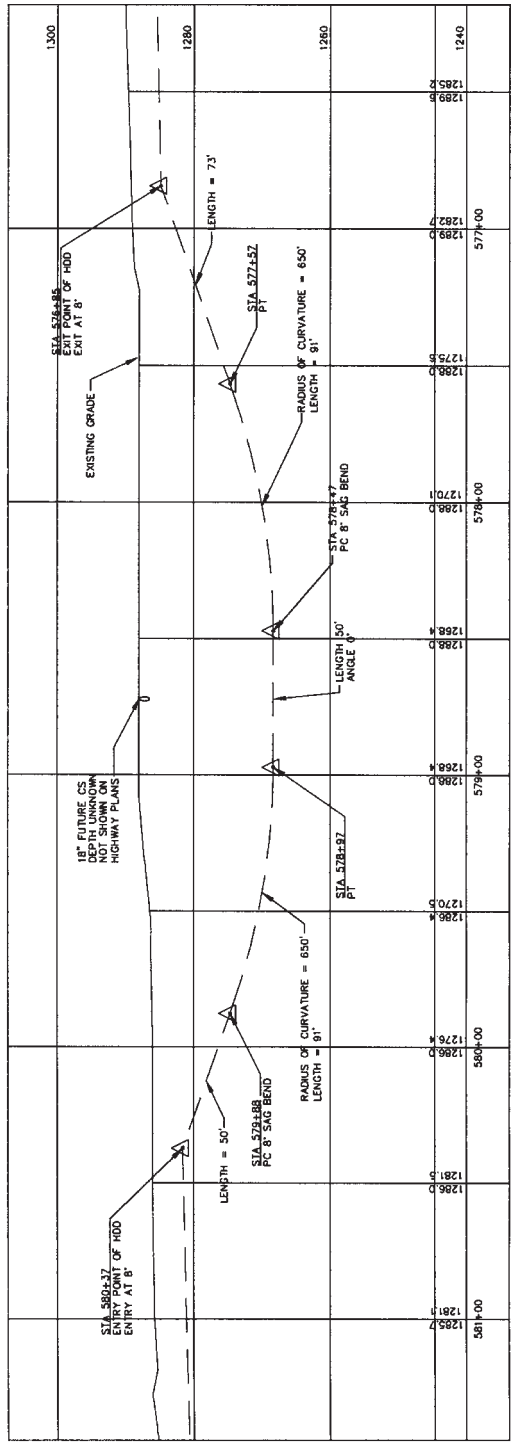

FIGURE 8.1 *(continued)* HDD plan and profile (profile).

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The length of the drill and the complexity of the strata determine the number of explorations holes required for the geotechnical survey. For drill paths shorter than 1000 feet, two soil test borings (one on each end of the bore) may be adequate. If the data from these test borings indicate that the conditions are likely to be homogeneous on both sides of the bore, it may not be necessary to conduct any more test borings. If the test data indicates anomalies or discontinuity in the soils conditions, or items such as large concentrations of gravel, further tests should be conducted. For drill paths longer than 1000 feet, soil test borings are typically taken at 700 foot intervals. The soil test bores should be near the drill-path to provide accurate soil data, but far enough from the drill path bore hole to avoid pressurized mud from following natural ground fissures and rupturing to the ground surface through the soil-test bore hole. A general rule is to take soil test bores at least 30 feet of either side of drill path. River crossings require additional information such as a study to identify riverbed depth, stability, and river width. Typically, pipes are installed to a depth of at least 20 feet below the river bottom. Soil test bores for geotechnical surveys under water are usually taken to a depth that is 20 feet deeper that the pipe drill path.

The earth material and subsurface stratification are the geotechnical classifications of interest in HDD projects. Earth material is the type and conditions of the soils material at the site. Subsurface stratification defines how the earth material is distributed throughout the site. For HDD projects, soil and rock are the broad categories for earth material. Soil particles vary in size and may contain water or air in the interstitial spaces and may be excavated without drilling or blasting. Rock is a hard, consolidated material, which may require drilling or blasting. The groundwater proximity (above or blow the pipe) may have an effect on the HDD construction as well as the in-service performance of the pipe. The groundwater table and potential fluctuation should be determined during the geotechnical survey.

Soil Type Classification

A qualified technician or geologist should classify the soil material. The Unified Soil Classification System is normally used in classifying soils for HDD projects. This soils classification system is described in detail in ASTM Standard D 2487. The ASTM Standard bases the soil classifications on laboratory tests performed on soil samples passing the 3 inch sieve. Some definitions from ASTM D 2487 that are relevant to HDD operations are:

Cobbles. Particles of rock that will pass a 12 inch square opening and be retained on a 3 inch U.S. standard sieve.

Boulders. Particles of rock that will not pass a 12 inch square opening.

Gravel. Particles of rock that will pass a 3 inch sieve and be retained on a No. 4 U.S. standard sieve with the following subdivisions: Coarse will pass a 3 inch sieve

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and be retained on a ¾ inch sieve and Fine, will pass a ¾ inch sieve and be retained on a No. 4 sieve.

Sand. Particles of rock that will pass a No. 4 sieve and be retained on a No. 200 U.S. standard sieve with the following subdivisions: Coarse will pass a No. 4 sieve and be retained on a No. 10 sieve; Medium will pass a No. 10 sieve and be retained on a No. 40 sieve; and Fine will pass a No. 40 sieve and be retained on a No. 200 sieve.

Clay. Soil that will pass a No. 200 U.S. standard sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents and that exhibits considerable strength when air dry.

Silt. Soil that will pass a No. 200 U.S. standard sieve that is non-plastic or slightly plastic and that exhibits little or no strength when air dry.

A general discussion of the Unified Soil Classification System is in *Geotechnical Engineers Portable Handbook* by Robert W. Day. Soil types have different factors that aid in the soils classification. The unit weight and moisture content are key factors for clay soils, while the density and grain size distribution are factors for granular soils. The standard penetration test (SPT) is used to define the density of granular materials. This is a field test that drives a 2 inch split spoon sampler into the soil by dropping a hammer of a specific weight (normally 140 lbs.) a specific distance (normally 30 inches) to determine the number of blows required to drive the sampler 12 inches. In dense soils the number of blows can be lowered (i.e. 3 inches). The number is called the standard penetration resistance value (N) and is used to estimate the relative density of cohesionless soils. Sometimes these penetration test are conducted in cohesive materials and rock, and to a lesser extent, the consistency of cohesive soils and the hardness of rock can be determined.

For rock soil conditions, the unit weight and hardness are key factors. If rock is located during the test borings it is important to determine the type, the relative hardness, and the unconfined compressive strength. The geotechnical firm collects this data by core drilling with a diamond bit core barrel. The geologist will classify the rock and determine the *rock quality designator* (RQD), which rates the quality of the rock based on the length of core retrieved in relation to the total length of the core. The hardness of the rock is determined by comparing the rock to ten materials of known hardness. Measuring the core and then compressing the core to failure determines the compressive strength.

The following are a few suggested guidelines concerning soil test bores to consider during the HDD planning stage:

- Get accurate locations and elevations for each exploration borehole
- Do not spot exploration boreholes directly over the proposed HDD path—offset each 25 feet to 30 feet laterally

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TABLE 8-3 Rock Quality Descriptions

RQD (%)	Rock Quality
90-100	Excellent
75-90	Good
50-75	Fair
25-50	Poor
0-25	Very Poor

- Request complete lithologic and geotechnic descriptions for all geologic strata encountered
- Require descriptions of boring techniques and all equipment used
- Test bores depths should go at least 20 feet below the lowest anticipated elevation of the horizontal directional borehole
- SPT's should be taken at 5 foot intervals for all strata (cohesive and non-cohesive units)
- Grain size analyses are helpful—either good field estimates or laboratory sieve tests
- It is important to get representative unconfined compression tests (UC) for all "harder" rock units that fail SPT tests (generally at "auger refusal"). Record RQD's and retain cores for visual inspection
- Have the driller or geologist record free water levels in the borings and note all significant observations during the actual drilling process. These notes should become part of the final log
- Have all boreholes thoroughly plugged and/or grouted upon completion of the exploration program

Surface Working Space

The surface impact associated with construction of a pipeline crossing by HDD is significantly less than the impact associated with construction by open cut excavation. However, the HDD construction is not without some surface impact. Working areas for the entry and exit points must be cleared and graded to allow for the HDD equipment and pipe pulling. The size of the area depends on the size of the drill and the drilling equipment to be used. Preferably each HDD site would allow at least 50 by 100 feet workspace for the entry side (drill rig) and adequate space on the exit side (pipe side) to pull the pipe as one continuous length. In urban areas this is often not possible. Because of restrictions such as lane closures for roads, or the need to work in alleyways, sidewalks, landscaped areas, or utility corridors, HDD equipment must often be configured in a linear arrangement. Other workspace considerations are the presence of overhead utilities and the possibility of restricted work-hours due to peak travel times on roadways.

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A typical large (Maxi) rig can require as many as seven tractor-trailer loads to transport all the equipment to the HDD site. A workspace of approximately 150 by 250 feet is normally adequate for most large HDD operations. If necessary, a rig may be installed in a workspace of 60 by 150 feet. However, a workspace this small restricts the size and capability of the drilling rig. A typical HDD site plan is shown in Figure 8.2.

DRILLED PATH DESIGN

When planning and designing a HDD crossing, a key factor is properly defining the obstacle that is to be crossed. A HDD project under a river can be significantly different that crossing a city road or other utilities. The site characterization will determine the entry and exit points, the length and depth of the drill, and the horizontal and vertical movements. The designed drill path will consist of a series of straight lines and curves. The straight lines are called tangents and the curves are typically sag bends, over bends, or side bends, depending on their axial plane. Compound bends may be used but are generally avoided to simplify the drill. The entry and exit points, entry and exit angles, radius of curvature, points of curvature, and tangency define the location and configuration of a drilled profile.

The entry and exit points are the end points of the drilled profile. The drill rig is positioned at the entry point and the drill path progresses from the entry to exit point. The product pipe is positioned at the exit point and is pulled into the hole at the exit point and pulled back to the entry point. The specific locations of the entry and exits points are determined based on the site characteristics and the drill path. Steering accuracy and drilling effectiveness are greater close to the drill rig (entry point). Whenever possible, the entry point should be located close to any anticipated adverse subsurface conditions.

Another factor is the workspace for pipe fabrication for the pull section. The preferred exit point will have enough workspace to assemble and pull the entire length of pipe in one continuous pull. If space is not available, the pipe may be fabricated in sections and pulled one section at a time. This is a slow installation that will increase cost and increase the chances of the pipe getting stuck during the pullback.

Entry angles are normally designed between 8-20 degrees with horizontal. This restriction is based on equipment limitations. When designing a HDD project, ensure that the entry and exit angles can be performed with the drill rig being used. Exit angles are designed to allow easy break-over support and to not over stress the product pipe. The exit angle should not be so steep that the pull section must be severely elevated in order to guide it into the hole.

CONSTRUCTION MONITORING

This section describes some of the construction-monitoring requirements relative to HDD operations. The primary objectives of construction monitoring on an HDD

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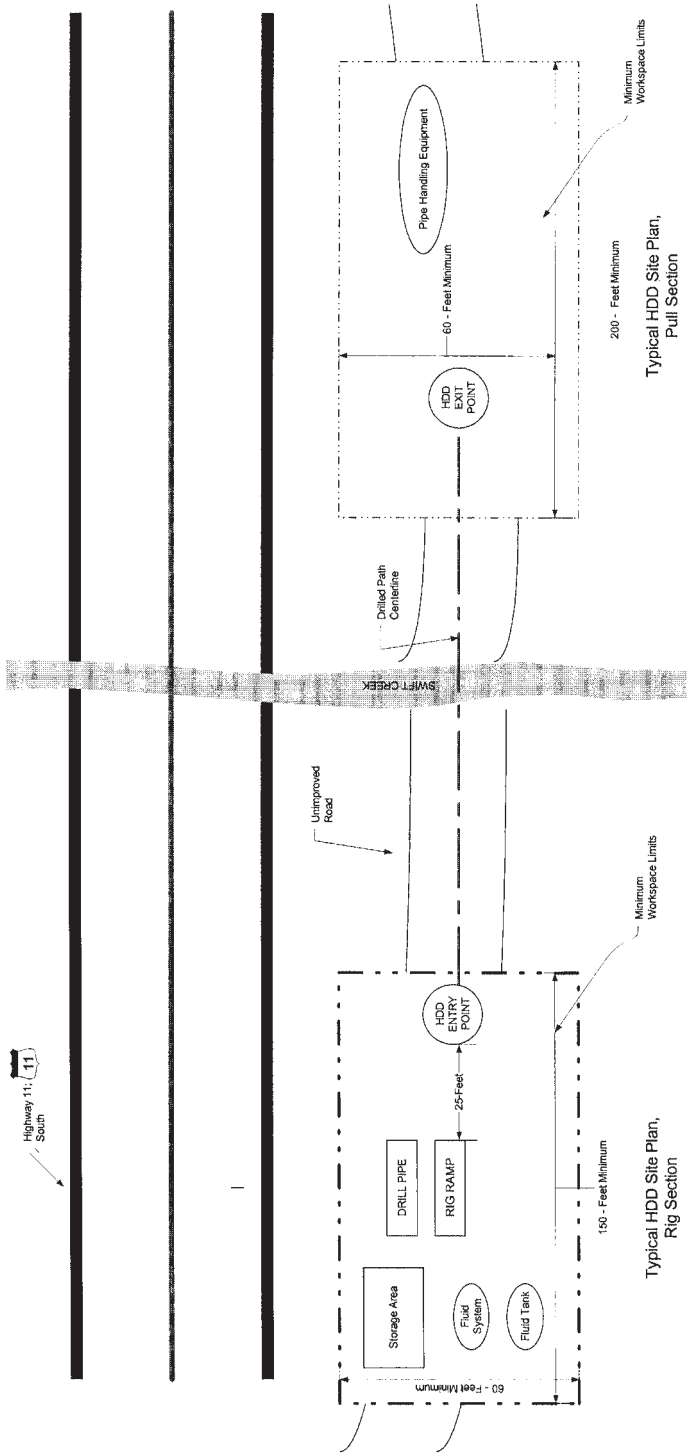

FIGURE 8.2 HDD site plan.

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installation are to ensure that the contractor interprets the contract and design documents properly, and to ensure that the actual drill is documented. In doing this, it is important for the inspector to document his observations and actions. Should a question or dispute arise during or after the installation, the inspector's notes will provide the only source of confirming data. Since a drilled installation is typically buried with deep cover, its installed condition cannot be confirmed by visual examination. Figure 8.3 is an example of HDD daily report.

Drilled Path

The drilling contractor will typically rely on the owner's staking to locate the drilled segment. Two locations, the entry and exit points, should be staked. The elevations of the staked locations as well as the distance between them should be checked against the values on which the design is based. The contractor's pilot hole accuracy depends on the accuracy of the relative location, both horizontally and vertically, of these two points. The exit point coordinates will also provide a benchmark for measuring downhole survey error. If possible, the contractor should have a clear line of sight between the entry and exit points for use in orienting the downhole survey instrument. If a clear line of sight is not possible, the owner should stake points so that the drilled path centerline, or a reference line, can be established for survey instrument orientation.

Pilot Hole

Monitoring of the drilled path is accomplished during pilot hole drilling. Initially, a reading of the magnetic heading is taken to establish a reference line on which

Daily Report		
Date:	Client:	Time In:
Percent Complete:	Project:	Time Out:
Description of Activities:		
Comments:		

FIGURE 8.3 HDD daily report.

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all drilled path data and calculations will be based. Other pertinent data which is needed to accurately locate the pilot hole drilling bit includes the bottom hole assembly length, the length from the drilling bit to the downhole probe, and the drilling rig setback distance from the entry point.

The actual path of the pilot hole is monitored during drilling by taking periodic readings of the inclination and azimuth of the downhole probe. Readings are typically taken after drilling a single joint, or approximately 30 feet. These readings are used to calculate the horizontal and vertical coordinates of the downhole probe as it progresses along the pilot hole. Data and calculations from the readings typically include the following items:

Survey. Points at which readings are taken by the downhole probe; surveys are usually tracked in a numerical sequence (1,2,3…) corresponding to the number of joints drilled.

Course Length. The distance between two downhole surveys as measured along the drilled path.

Measured Length. The total distance of a downhole survey from the entry point as measured along the drilled path; also the summation of the course lengths.

Inclination. The angle at which the downhole probe is projecting from the vertical axis at a particular downhole survey point; vertically downward corresponds to zero degrees.

Azimuth. The angle at which the downhole probe is projecting in the horizontal plane at a particular downhole survey point; magnetic north corresponds to zero degrees.

Station. The horizontal position of a downhole survey measured from an established horizontal control system.

Elevation. The vertical position of a downhole survey measured from an established vertical control system.

Right. The distance of a downhole survey from the design path reference line. Positive values indicate right of the reference line while negative values indicate left of the reference line.

Bit to Probe. The distance from the drilling bit (leading edge) to the downhole probe.

Heading. The magnetic line of azimuth to which the drilled path reference line corresponds.

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Rig Setback. The distance from the drill bit when first placed on the drilling rig as measured from the staked entry point.

BHA Length. The length of the bottom hole assembly.

HDD PERFORMANCE

There are two basic areas of concern with HDD performance, the position and curvature of the pipeline. First, the pipeline must be installed so that the drilled length, depth of cover, and entry/exit angles specified by the design are achieved. Second, the installation must not curve the drilled path in such a way that the pipeline will be damaged during installation or over stressed during operation. The actual position of the drilled path cannot be readily confirmed by an independent survey. Therefore, it is necessary to have a basic understanding of the downhole survey system being used and be able to interpret the readings. It is not necessary to observe and approve the drilling of each joint. However, progress should be monitored on a routine basis and problems addressed so that remedial action can be taken as soon as possible. The inspector should insure that bends are not drilled which have a radius of curvature less than the design (minimum allowable). Figure 8.4 illustrates an example of a HDD survey report. Figure 8.5 is an an example of a radius of curvature anylsis. If a tight radius occurs, the joint or joints should be re-drilled or reviewed with the design engineers as soon as possible to insure that the codes and specifications governing design of the pipeline are not violated.

Downhole Survey Calculations

Downhole survey calculation methods are discussed in detail in API Bulletin D20. Three different methods from this bulletin are presented here for use on HDD pipeline installations. These are:

1. Average angle
2. Balanced tangential method
3. Minimum curvature

The equations for these three methods are used to calculate the horizontal and vertical distances from the entry point, as well as the distance from the reference line. Symbols used in the equations are defined below:

CL = Course length.
I_1 = Inclination angle of the previous survey point.
I_2 = Inclination angle of the current survey point.
A_1 = Deflection angle from the heading of the previous survey point.
A_2 = Deflection angle from the heading of the current survey point.

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Survey Tabulation Sheet											
Date:		Bit to Probe:		Azimuth:			Rig Setback:		BHA Length:		
Raw Data				TruTracker Data			Calculations				
Survey #	Joint Length	Inclination Angle	Azimuth	Right	Elevation	Measured Distance	Station	Right	Elevation		

FIGURE 8.4 HDD survey tabulation sheet.

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Radius of Curvature Analysis					
Date:	Project:				
Notes:					
Radius of Curvature Per N Surveys					
Survey #	1	3	5	7	10

FIGURE 8.5 HDD radius of curvature analysis.

HD = Horizontal distance between the previous and current survey points.

RT = Differential distance from the reference line between the previous and current survey points. Also called "RIGHT" to indicate the distance right (positive value) or left (negative value) of the original reference line.

VT = Vertical distance between the previous and current survey points.

Average Angle Method

This method uses the average of the previous and current azimuth/inclination angles to project the measured distance along a path that is tangent to this average angle. The equations are:

$$HD = CL \times \cos\frac{(A_1 + A_2)}{2} \times \sin\frac{(I_1 + I_2)}{2} \tag{8.1}$$

$$RT = CL \times \sin\frac{(A_1 + A_2)}{2} \times \sin\frac{(I_1 + I_2)}{2} \tag{8.2}$$

$$VT = CL \times \cos\frac{(I_1 + I_2)}{2} \tag{8.3}$$

Balanced Tangential Method

This method assumes that half of the measured distance is tangent to the current inclination/azimuth projections and that the other half is tangent to the previous inclination/azimuth projections.

$$HD = \sqrt{\frac{CL}{2}}(\sin I_1 \cos A_1 + \sin I_2 \sin A_2) \tag{8.4}$$

$$RT = \sqrt{\frac{CL}{2}}(\sin I_1 \sin A_1 + \sin I_2 \sin A_2) \tag{8.5}$$

$$VT = \sqrt{\frac{CL}{2}}(\cos I_1 + \cos A_2) \tag{8.6}$$

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Minimum Curvature Method

This method is similar to the Balanced Tangential Method; however, the tangential segments produced from the previous and current inclination/azimuth angles are smoothed into a curve using a ratio factor (RF). This ratio factor is defined by a dogleg angle (DL), which is a measure of the change in inclination/azimuth.

$$DL = \cos^{-1}\{\cos(I_2 - I_1) - \sin I_1 \times \sin I_2[1 - \cos(A_2 - A_1)]\} \tag{8.7}$$

$$RF = \sqrt{\frac{2}{DL}} \tan \sqrt{\frac{DL}{2}}; \text{ RF = 1 for small angles (DL < 0.25 degrees)} \tag{8.8}$$

$$HD = \sqrt{\frac{CL}{2}}(\sin I_1 \cos A_1 + \sin I_2 \sin A_2)RF \tag{8.9}$$

$$RT = \sqrt{\frac{CL}{2}}(\sin I_1 \sin A_1 + \sin I_2 \sin A_2)RF \tag{8.10}$$

$$VT = \sqrt{\frac{CL}{2}}(\cos I_1 + \cos A_2)RF \tag{8.11}$$

Any one of these three methods may be used to track the downhole probe position and ensure conformance to the directional tolerances of the design. To track the probe over a specified measured distance the values from these equations must be summed over the specified length.

Radius of Curvature Calculations

The same angle readings used in the previous calculations are also used to determine the radius of curvature of the drilled path. The radius of curvature calculations are based on the relationship:

$$R = \frac{s}{Q}$$

where s = arc length in feet
Q = angular distance in radians

For a specific drilled length, the radius of curvature is calculated using the following formula:

$$R_{\text{drilled}} = \sqrt{\frac{I_{\text{drilled}}}{q_{\text{drilled}}}} \times \sqrt{\frac{180}{\pi}} \tag{8.12}$$

where R_{drilled} = the radius of curvature over a specified drill length in feet
I_{drilled} = drilled length in feet
q_{drilled} = change in angle over the drilled length in degrees

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Typically, the radius of curvature is checked for conformance over any three joint course lengths using the following equation:

$$R_3 = \sqrt{\frac{L_3}{Q_3}} \times \sqrt{\frac{180}{\pi}} \tag{8.13}$$

where R_3 = the radius of curvature in feet over L_3.
L_3 = course length in feet over any 3 joint, no less than 75-feet and no greater than 100-feet.
Q_3 = total change in angle in degrees over L_3.

PIPE INSTALLATION

The inspector should review the contractor's operations to insure that the pull section is adequately supported during pull back. Roller stands should be provided as well as lifting equipment capable of moving the string into the drill hole. The section should not be dragged on the ground. All break over bends should be made with a radius long enough to insure that the pipe is not over stressed.

The inspector should always bear in mind the possibility of inadvertent drilling fluid returns. The right of way should be examined regularly for inadvertent returns. Particular attention should be paid to locations of underground utilities and pile foundations. If inadvertent returns are found, they should be cleaned up immediately and the location monitored for continuing problems (particularly during pull back).

HDD STRESSES AND FORCES

After completion of the geotechnical investigation and determination that HDD is feasible, the designer turns attention to designing a proper drill and selecting the proper pipe. The product pipe must satisfy all the requirements of the project including flow capacity, working pressure rating, and surge or vacuum capacity. These considerations have to be met regardless of the method of installation. For HDD applications, in addition to the service life operating requirements, the pipe must be able to withstand pull-back loads, which include tensile pull forces, external hydrostatic pressure, and tensile bending stresses. The pipe must also withstand external service loads which consist of post-installation soil, groundwater, and surcharge loads occurring over the life of the pipeline. Often the load the pipe sees during installation, such as the combined pulling force and external pressure will be the largest load experienced by the pipe during its life.

Load and stress analysis for a HDD project are different from similar analyses for buried pipelines. Pipe properties such as wall thickness and material grade must be selected so the pipeline can be installed and operated as planned. Directional drilling is an evolving technology and industry-wide design standards are

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still developing. Proper design requires considerable professional judgment. The most frequently asked questions are:

- What force is required to pull the pipe through the borehole?
- How much pulling force can be applied to the product pipe?

The pipe manufacturer can usually answer the second question. However, the force required to pull the pipe through the borehole has many factors such as:

- Borehole diameter
- Product pipe diameter
- Soil conditions
- Drilling fluid characteristics
- HDD and pullback procedures being used
- Drill path profile and radius of curvature

These factors are often site and job specific, and the pulling force required should be determined by experienced engineers, drillers, and geotechnical personnel that are familiar with the site conditions and HDD procedures.

The bore path has a significant impact in the forces acting on the pipe during pullback. The straighter the profile and alignment, the less the pulling force. Curvature in the pipe is necessary to get under or around the obstacles, but curvature should be minimized. The curvature causes bending stresses in the drill rods and the product pipe, and due to the increased friction, increases the pullback forces. When selecting the bore path, the designer has to consider the site characteristics and the allowable bending stresses in the product pipe. Based on many factors, the designer then develops a preliminary drill path that will successfully negotiate the obstacle without imposing excessive stresses or pullback forces on the product pipe.

Another key factor in the drill path is the depth of the drill profile. The profile must be deep enough to ensure any obstacles are cleared by the desired distance. Also, a minimum depth for the drill path is required to ensure that no drilling fluid breakout occurs. For mini-HDD operations this depth is typically 3 feet or more, but this depends on the site-specific soil conditions. Normally, the bore profile arcs down from the entry point, then straightens out before it finally arcs back up to the exit point.

During installation, the product pipe is subjected to:

- Tension that is required to pull the pipe into the pilot hole and around the curved sections that make up the bore path. Frictional drag due to the wetted friction between the pipe and wall of the borehole
- Fluidic drag of the pipe as it is pulled through the viscous drilling fluid trapped in the annulus
- Unbalanced gravity (weight) effects of pulling the pipe into and out of a borehole at different elevations

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- Bending as the pipe is forced to negotiate the curves in the borehole
- External hoop from the pressure exerted by the drilling mud in the annulus around the pipe (unless the pipe is filled with a fluid at a similar pressure)

The stresses and potential failure of the pipe are a result of the relations of these loads. As a result, calculations of the individual effects do not accurately reflect the combined stresses. These combined stresses require specific calculations and design checks. The loads imposed on a pipe during operation are significantly different than the loads the pipe will see during installation by HDD.

HDD DESIGN CONSIDERATIONS FOR PLASTIC PIPE

After determining the pipe properties required for long-term service, the designer must determine if the pipe properties are sufficient for installation. Since installation forces are so significant, a stronger pipe may be required because of the installation stresses. Proper installation procedures may reduce some of these forces to an inconsequential level. During pullback, the pipe is subjected to axial tensile forces caused by the frictional drag between the pipe and the borehole or slurry, the frictional drag on the ground surface, the capstan effect around drill-path bends, and hydrokinetic drag. In addition, the pipe may be subjected to external hoop pressures due to net external fluid head and bending stresses. The axial pulling force reduces the pipe collapse resistance to external pressure. Furthermore, the pipe-bending radius may limit the drill path curvature. Torsional forces occur but are usually negligible when back-reamer swivels are properly designed. As discussed previously, considerable judgment is required to predict the pullback force because of the complex interaction between pipe and soil. Sources for information include experienced drillers, engineers, and publications. Typically, pullback force calculations are approximations that depend on considerable experience and judgment. Because of the large number of variables involved and the sensitivity of pullback forces to installation techniques, the formulas presented in this section are for guidelines only, and are given only to familiarize the designer with the interaction that occurs during pullback. Pullback values obtained should be considered only as qualitative values and used only for preliminary estimates. The designer is advised to consult with an experienced driller or with an engineer familiar with calculating these forces.

Pull Back Force

Large HDD rigs can exert between 100,000 to 200,000 pounds of pull force. The majority of this power is applied to the cutting face of the reamer, which precedes the pipeline segment into the borehole. It is difficult to predict what portion of the total pullback force is actually transmitted to the pipeline being inserted. The pulling force that overcomes the combined frictional drag, capstan effect, and hydrokinetic

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drag, is applied to the pull-head and first joint of pipe. The axial tensile stress grows in intensity over the length of the pull. The duration of the pull load is longest at the pull-nose. The tail end of the pipe segment has zero applied tensile stress for zero time. The incremental time duration of stress intensity along the length of the pipeline from nose to tail causes a varying degree of recoverable elastic strain and viscoelastic stretch per foot of length along the pipe. The pipe wall thickness must be selected so that the tensile stress due to the pullback force does not exceed the permitted tensile stress for the pipe. Increasing the pipe wall thickness will allow for a greater total pull-force, but the thicker wall also increases the weight per foot of the pipe in direct proportion. As a result, thicker wall pipe may not necessarily reduce stress. It may only increase the absolute value of the pull force or tonnage. The designer should carefully check all proposed pipe wall thicknesses and properties.

Frictional Drag Resistance

Pipe resistance to pullback in the borehole depends primarily on the frictional force created between the pipe and the borehole, the pipe and the ground surface in the entry area, the frictional drag between pipe and drilling slurry, the capstan effect at bends, and the weight of the pipe. The following equation gives the frictional resistance or required pulling force for pipe pulled in straight, level bores, or across level ground.

$$F_p = cW_BL \tag{8.14}$$

where F_p = pulling force, lbs
c = coefficient of friction between pipe and slurry (typically 0.25) or between pipe and ground (typically 0.40).
W_B = net downward (or upward) force on pipe, lb/ft
L = length, ft

When a slurry is present, W_B, is the upward buoyant force of the pipe and its contents. Filling the pipe with fluid significantly reduces the buoyancy force and thus the pulling force. If the pipe is installed empty using a closed nose-pull head, the pipe will want to float on the crown of the borehole leading to the sidewall loading, increasing frictional drag through the buoyancy-per-foot force and the wetted soil to pipe coefficient of friction. If the pipe is installed full of water the net buoyant force is drastically reduced. During pullback, the moving drill mud lubricates the contact zone. If the drilling stops, the pipe stops, or the mud flow stops, the pipe can push up and squeeze out the lubricating mud.

Capstan Force

For curves in the borehole, the force can be factored into horizontal and vertical components. When drilling with steel pipe there is an additional frictional force that

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occurs due to the pressure required by the borehole to keep the steel pipe curved. When drilling with plastic pipe using a radius of curvature similar to that used for steel pipe, these forces are likely insignificant. However, when using tight bends, these forces should be taken into consideration. The frictional resistance during a pull is compounded by the capstan effect. Compounding forces caused by the direction of the pulling vectors are created as the pipe is pulled around a curve or bend creating an angle. The pulling force due to the capstan effect is given in the following equation. This equation and the preceding one are applied recursively to the pipe for each section along the pullback distance. This method is credited to Larry Slavin of Bellcore (Middletown, NJ).

$$F_c = e^{\mu\phi}(\mu W_B L) \tag{8.15}$$

where e = Natural logarithm base ($e = 2.71828$)
μ = Coefficient of friction between the pipe and slurry or between the pipe and ground
ϕ = Angle of bend in pipe, radians
W_B = Weight of pipe or buoyant force on pipe, lbs/ft
L = Length of pull, ft

The majority of HDD bore paths consist of a series of straight sections and bends. To estimate the total pull forces, the above equations must be applied to each straight section and bend, and totaled. The following is a method developed by Larry Slavin for estimating the loads along a bore path with no horizontal bends. This method is an estimate only. The designer or engineer must determine their suitability for any application

$$T_D = (v_b\beta)(T_C + T_{HK} + v_b|w_b|L_4 - w_bH - \exp(v_b\alpha)(v_aw_aL_4\exp(v_a\alpha)) \tag{8.16}$$

$$T_A = \exp(v_a\alpha)(v_aw_a(L_1 + L_2 + L_3 + L_4)) \tag{8.17}$$

$$T_B = \exp(v_b\alpha)(T_A + T_{HK} + v_b|w_b|L_2 + w_bH - v_aw_aL_2\exp(v_a\alpha)) \tag{8.18}$$

$$T_C = T_B + T_{HK} + v_b|w_b|L_3 - \exp(v_a\alpha)(v_aw_aL_3\exp(v_a\alpha)) \tag{8.19}$$

where T_A = pull force on pipe at point a, lbf
T_B = pull force on pipe at point b, lbf
T_C = pull force on pipe at point c, lbf
T_D = pull force on pipe at point d, lbf
T_{HK} = Hydrokinetic force, lbf (see below equation for this factor
L_1 = additional length of pipe required for handling and thermal expansion/contraction, feet
L_2 = horizontal distance to desired depth, feet
L_3 = addtional distance traversed at desired depth, feet
L_4 = horizontal distance to rise to the surface, feet
H = depth of borehole from ground surface, feet
$\exp(x) = e^x$, where e = natural logarithm base ($e = 2.71828$)

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v_a = coefficient of friction applicable at the surface before the pipe enters borehole, typically 0.5
v_b = coefficient of friction applicable within the lubricated borehole or after the wet pipe exits, typically 0.3
w_a = weight of empty pipe, lbf/ft
w_b = net upward buoyant force on the pipe in borehole, lbf/ft
a = borehole angle at pipe entry (drill exit angle), radians
b = borehole angle at pipe exit (drill entry angle), radians

The previous equations are approximations. They do not accurately account for the resistance due to pipe stiffness at curves along the bore path. The pull forces will be reduced for large radius curves and larger clearance within the borehole. The designer or engineer should ensure that the estimated pull forces do not over stress the product pipe.

GUIDELINES AND SPECIFICATIONS FOR INSTALLATION BY HDD TECHNOLOGY

This section contains practices, which are summarized and categorized chronologically beginning at the pre-qualification stage and ending with post-construction evaluation. Special sections are devoted to selected topics including segment joining, tie-ins, and the handling and disposal of drilling mud slurry.

Contract Considerations

Sharing risk with the contractor can significantly reduce the average bid price on a project. This is particularly true in underground construction. Items that should be addressed in contracts involving HDD work may include:

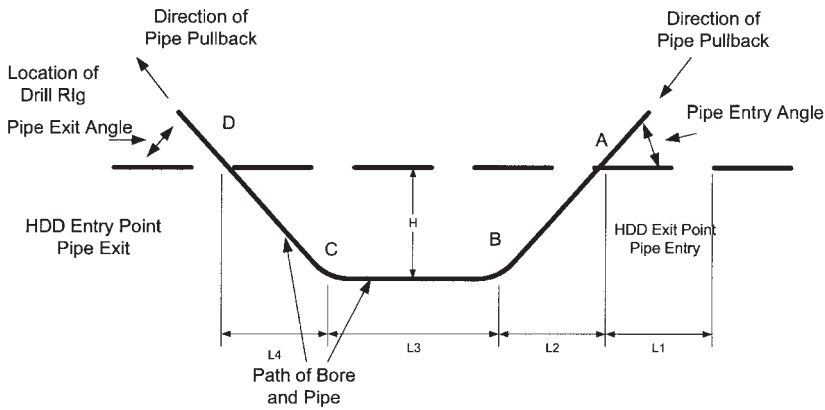

FIGURE 8.6 HDD bore path.

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Different Ground Conditions and Walk-Away Provision. Adequate geo-technical information is invaluable in underground construction and can help to reduce the contractor's risk. However, even with good geo-technical data unexpected ground conditions may be encountered. These conditions can make it difficult, or even impossible, to complete the crossing using the HDD method. The contract should include provisions for if a project encounters unexpected ground conditions. Walk-away provisions in the contract entitle the contractor to stop working and walk-away from the job without penalty provided the contractor demonstrated a diligent effort to complete the project and it was decided to abandon the method.

Turbidity of Water and Inadvertent Returns. Difficult to predict these events may lead to work stoppage and loss of equipment. The contract should offer a mechanism to mutually address and mitigate these problems if and when they arise. For example, contingency plans for containment and disposal of inadvertent returns can be priced as a separate bid price and agreed prior to construction.

Contractor Proposal/Bid

As part of the bid, each HDD contractor should provide the following items:

- Construction plan
- Site layout plan
- Project schedule
- Communication plan
- Safety manual/procedures
- Emergency procedures
- Company experience record
- List of subcontractors on the project
- Drilling fluid management plan

Construction Plan

The following information should be submitted with respect to the construction plan:

- Access requirements to the site
- Type and capacity of drilling rig to be use on the project including thrust and rotary torque. The size of the drilling equipment should be adequate for the job. An industry rule of thumb is that the drilling rig's pull/push capacity should be at least equal to twice the weight of the product to be pulled or the weight of the drilling rod in the hole, which ever is greater. It should be noted that the range of a particular rig for a particular product type can vary significantly depending on soil conditions, drill path profile (i.e., radius of curvature) and crew experience

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- Type and capacity of the mud mixing system. This is of particular importance if at least part of the bore path is suspected to consist of solid rock or the final ream has a diameter of 14 inches or greater
- A listing of any specialized support equipment required
- Project schedule indicating the various tasks and their expected duration
- Drawing of work site indicating the location and footprints of all equipment, location of entry and exit pits, and location of slurry containment pits
- Construction method including: diameter of pilot hole; number and size of pre-reams; use of rollers, baskets and side booms to suspend and direct pipe during pull back; number of sections in which product is to be installed
- Type, operating range and degree of accuracy of tracking equipment

Drilling Fluids Management Plan

The following information should be provided as part of the drilling fluid management plan:

1. Identify source of fresh water for mixing the drilling mud. Necessary approvals and permits are required for sources such as streams, rivers, pounds or fire hydrants
2. Method of slurry containment
3. Method of recycling drilling fluid and spoils
4. Method of transporting drilling fluids and spoils off the site
5. Approved disposal site for drilling mud and spoils

Previous Experience

The bidder should provide a list of similar projects completed by his company, including name of owner, location, project environment (e.g., urban work, river crossing), product diameter, length of installation, contact name and telephone number.

The bidder should also provide a list of key personnel assign to the project including their title, experience record and personal references.

Safety

Each bidder should submit a copy of the company safety manual including:

- Operating procedures that comply with applicable regulations, including shoring of pits and excavations when required
- Emergency procedures for inadvertently boring into natural gas line, live power cable, water mains, sewer lines, or fiber-optic cables which comply with applicable regulations
- Emergency evacuation plan in case of an injury

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The drilling unit must be equipped with an electrical strike safety package. The package must include:

- Warning sound alarm
- Grounding mats
- Protective gear.

Contingency Plans

Contingency plans should consist of the following:

- Contingency plan in case of spill (e.g., drilling fluids, hydraulic fluids), including measures to contain and clean the affected area
- A contingency plan for the clean up of surface seepage of drilling fluids and spoils
- Specific action(s) required to be taken in the event that the installed pipe fails the post-installation leak test

Communication Plan

The communication plan should address the following items:

- The form and frequency of communication with owner or his representative on the site
- Identification of key person(s) which will be responsible to ensure that the communication plan is followed
- Issues to be communicated including safety, progress, and unexpected technical difficulties

Traffic Control

Traffic control considerations are as follows:

- When required, the contractor at his cost shall be responsible for supplying and placing warning signing, barricades, safety lights and flags or flagmen, as required for the protection of pedestrians and vehicle traffic
- Obstruction of the roadway should be limited to off-peak hour on major roads

List of Subcontractors

Subcontractors and their designated tasks should be identified. Possible tasks to performed by subcontractors include:

- Utility location
- Hydro-excavation

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- Pipe suppliers
- Leak testing
- Fusion / welding
- Tie-ins to services and / or mains
- Mud mix disposal
- Excavation of entry / exit pits
- Surface restoration such as pavement, sidewalks and lawns

Other Considerations

Other requirements to be addressed in the bid include permits requirements:

- Permits necessary for a contractor to carry on a business
- Street opening (cut) permits
- Use of hydrants for water
- Permits for storage, piling, and disposal of material
- Permits for water/bentonite disposal
- Any other permits required to carry out the work

SITE EVALUATION

The HDD location should be inspected prior to the commencing of the project. The following should be addressed:

- Establishing whether or not there is sufficient room at the site for, entrance and exit pits, HDD equipment and its safe and unimpeded operation, support vehicles, fusion machines, and stringing out the pipe to be pulled back in a single, continuous operation
- Establishing suitability of soil conditions for HDD operations. The HDD method is ideally suited for soft sub-soils such as clays and compacted sands. Subgrade soils consisting of large grain materials like gravel and cobble and boulders make HDD difficult to use and may contribute to damaging the pipe
- Check the site for evidence of substructures such as manhole covers, valve box covers, meter boxes, electrical transformers, conduits or drop lines from utility poles, and pavement patches. HDD may be a suitable method in areas where the substructure density is relatively high

Pre-Construction

The followings are steps that should be undertaken by the contractor in order to ensure a safe and efficient construction with minimum interruption to normal every day activities at the site:

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- Notify owners of subsurface utilities along and on either side of the proposed drill path of the impending work through the one-call program. Locate all utilities along and on either side of the proposed drill path
- Obtain all necessary permits or authorizations to carry construction activities near or across all such buried obstructions
- All utility crossings shall be exposed using a hydro-excavation, hand excavation or another approved method, to confirm depth
- Construction schedule should be arranged as to minimize disruption
- The proposed drill path should be determined and documented, including its horizontal and vertical alignments, location of buried utilities and substructures along the path
- Size of excavation for entrance and exit pits are to be of sufficient size as to avoid a sudden radius change of the pipe, and consequently excessive deformation at these locations. Sizing the pits is a function of the pipe depth, diameter and material. All pits must be shored as required by the relevant regulations

Drilling Operations

The following list provides general remarks and rules of thumb related to the directional boring method, as well as specific details regarding various stages along the installation process:

- Only trained operators should be permitted to operate the drilling equipment. They should always follow the manufacture's operating instructions and safety practices
- Drilling mud pressure in the borehole should not exceed that which can be supported by the overburden to prevent heaving or a hydraulic fracturing of the soil (i.e., 'Frac-out'). Allowing for a sufficient cover depth helps accomplishes this
- The drill path alignment should be as straight as possible to minimize the fractional resistance during pullback and maximize the length of the pipe that can be installed during a single pull
- It is preferable that straight tangent sections will be drilled before the introduction of a long radius curve. Under all circumstances, a minimum of one complete length of drill rod should be utilized before starting to level out the borehole path
- The radius of curvature is determined by the bending characteristics of the product line
- Entrance angle of the drill string should be between 8 and 20 degrees, with 12 degrees being considered optimal. Shallower angles may reduce the penetrating capabilities of the drilling rig, while steeper angles may result in steering difficulties, particularly in soft soils. A recommended value for the exit angle of the drill string is in the range of 5 to 10 degrees

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- Whenever possible, HDD installation should be planned so that back reaming and pulling for a leg can be completed on the same day. It is permissible to drill the pilot hole and pre-ream one day, and complete both the final ream and the pull back on the next day
- If a drill hole beneath a road must be abandoned, the hole should be filled with grout or bentonite to prevent future subsidence
- Pipe installation should be performed in a manner that minimizes the over-stressing and straining of the pipe. This is of particular importance in the case of a polyethylene pipe

Equipment Setup and Site Layout

- Sufficient space is required on the rig side to safely setup and operate the equipment. The workspace required depends on the type of rig used. A mini rig may require as little as 10x10 feet of working space, while a large river crossing unit requires a minimum of 100x150 feet of working area. A working space of similar dimensions to that on the rig side should be allocated on the pipe side, in case there is a need to move the rig and attempt drilling from this end of the crossing.
- If at all possible the crossing should be planned to ensure that drilling proceeds downhill, allowing the drilling mud to remain in the hole and minimizing inadvertent return.
- Sufficient space should be allocated to fabricate the product pipeline into one string, thus enabling the pull back to be conducted in a single continuous operation. Tie-ins of successive strings during pullback may considerably increase the risk of unsuccessful installation.

Drilling and Back-Reaming

- Drilling mud should be used during drilling and back reaming operations. Using water only may cause collapse the borehole in unconsolidated soils, while in clays the use of water may cause swelling, and subsequent jamming of the product
- Heaving may occur when attempting to back reaming too large of a hole. This can be avoided by using several pre-reams to gradually enlarge the hole to the desired diameter
- A swivel should be attached to the reamer, or drill rod, to prevent rotational torque been transferred to the pipe during pullback
- In order to prevent over-stressing of the product during pullback, a weak link, or breakaway pulling head, may be used between the swirl and the leading end of the pipe

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- The pilot hole must be back-reamed to accommodate and permit free sliding of the product inside the borehole. A rule of thumb is to have a borehole 1.5 times the product outer diameter. This rule of thumb should be observed particularly in the larger diameter installations
- The conduit must be sealed at either end with a cap or a plug to prevent water, drilling fluids, and other foreign materials from entering the pipe as it is being pulled back
- Pipe rollers, skates, or other protective devices should be used to prevent damaging the pipe from the edges of the pit during pull-back, eliminate ground drag, and reduce pulling force and subsequently the stress on the product
- The drilling mud in the annular region should not be removed after installation, but permitted to solidify and provide support for the pipe and neighboring soil

Segment Jointing (Butt-Fusion/Welding)

- The contractor shall perform a leak test on the pipeline (particularly on fused joints) prior to pipe pull back
- It may be necessary to remove the lip on the butt fusion connections to prevent snagging on potential obstructions
- A qualified fusion technician should do all joining in accordance with the pipe manufacturers specifications
- Standard inspection techniques should be followed for assessing quality of butt and electro fusion joints

Tie-Ins and Connections

- Trenching should be used to join sections of conduits installed by the directional boring method. Trenching to join conduits shall be at the contractor's expense and should be included in the unit rate
- An additional pipe length, sufficient for joining to the next segment, should be pulled into the entrance pit. This length of the pipe should not be damaged or interfere with the subsequent drilling of the next leg. The contractor should leave a minimum of 3 feet of conduit above the ground on both sides of the borehole
- In the case of a PE pipe, tie-ins and connections should only be made after a suitable time period in order to allow the pipe to recover. Ideally, the pipe should be allowed to recover overnight. If this is not possible, the recovery period should be equal to at least twice the pull back time

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Alignment and Minimum Separation

In all cases, the product shall be installed to the alignment and elevations as shown on the drawings within pre-specified tolerances. However, tolerance values are application dependent. For example, in a major river crossing a tolerance of 12 feet from the exit location along the drill path centerline may be an acceptable value. However, this tolerance is not acceptable when installing a product line between manholes. Similarly, grade requirements for a water force-main are significantly different than these on a gravity sewer project. It is recommended that a study will be initiated in order to establish tolerance limits for various applications that are acceptable from the design point of view and at the same time achievable using current tracking and steering capabilities of HDD equipment.

When a product line is installed in a crowded right-of-way, the issue of safe minimum separation distance arises. Many utilities companies have establish regulations for minimum separation distances between various utilities. These distances needed to be adjusted to account for possible minor deviation when a line product is installed using HDD technology. As a rule of thumb, if the separation distance between the proposed alignment and the existing line is 10 feet or more, normal installation procedures can be followed. If the separation is 5 feet or less, special measures, such as observation boreholes are required. The range between 5 and 10 feet is a gray area, typically subject to engineering judgment. A natural gas transmission line is likely to be treated more cautiously than a storm water drainage line.

Break-Away Pulling Head

Recent reports from several natural gas utility companies reveals concerns regarding failure experiences on HDPE pipes installed by horizontal directional drilling. These failures were attributed to deformation of the pipe due to the use of excessive pulling force during installation. A mitigation measure adopted by some gas companies involves the use of break-a-way swivels to limit the amount of force used when pulling PE products. The weak link used can be either a small diameter pipe (but same SDR) or specially manufactured breakaway links. The latter consists of a breaking pin with a defined tensile strength incorporated in a swivel. When the strength of the pin is exceeded, it will break causing the swivel to separate. The use of breakaway swivels is warranted particularly when installing small diameter PE pipes (up to 4-inches OD).

Application of such devices in the installation of larger diameter products is currently not a common practice. If the drilling equipment rated, pulling capacity is less than the safe load and the use of a weak link may not be required. Exceeding the product elastic limit can be avoided simply by following the following good drilling practices:

- Regulating pulling force
- Regulating pulling speed

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- Proper ream sizing
- Appropriate amounts of drilling slurry fluid

Drilling Fluid—Collection and Disposal Practices

The collection and handling of drilling fluids and inadvertent returns is perhaps one of the most debated topics in the HDD community in North America. On one side the industry realizes the need to keep drilling fluids out of streams, streets and municipal sewer lines. On the other hand new tough regulations in some states (i.e., California) faced HDD contractors with escalating drilling fluid disposal expenses. Owners need to adopt an approach which address environment concerns while at the same time avoid unnecessary expenses and escalating drilling rates. The following clauses can be used as a guideline for the development of such an approach.

1. Drilling mud and additives to be use on a particular job should be identified in the proposal, and their Material Safety Data Sheets (MSDS) provided to the owner
2. Excess drilling mud slurry shall be contained in a lined pit or containment pond at exit and entry points, until recycled or removed from the site. Entrance and exit pits should be of sufficient size to contain the expected return of drilling mud and spoil
3. Methods to be used in the collections, transportation, and disposal of drilling fluids and spoils are to be provided as part of the pre-qualification. Excess drilling fluids should be disposed in compliance with local ordinances, regulations, and environmentally sound practices in an approved disposal site
4. In working in an area of contaminated ground, the slurry should be tested for contamination, and disposed in a manner that meets government requirements
5. Precautions should be taken to keep drilling fluids out of the streets, manholes, sanitary and storm sewers, and other drainage systems, including streams and rivers
6. Recycling drilling fluids is an acceptable alternative to disposal
7. The contractor shall make all diligent efforts to minimize the amount of drilling fluids and cuttings spilled during the drilling operation, and shall provide complete clean-up of all drilling mud overflows or spills

Site Restoration and Post Construction Evaluation

Site restoration and evaluations are the critical closing elements of HDD projects.

- It is recommended that the pipe be inspected for damage at every excavation pit as it being pulled back and after the installation is complete

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- All surfaces affected by the work shall be restored to their pre-construction conditions. Performance criteria for restoration work are to be similar to these employed in traditional open excavation work
- Performance specifications should be developed as to hold the contractor responsible for settlement/heave damage that may occur along the drill path
- It is recommended that an additional length of the pipe that is one percent of the length, or 5 feet, whichever is greater, be pulled through the entrance pit, exposed, and examined for scratches, scores, cuts or other forms of damage. If excessive damage is found, a second additional pipe length, equal to the first length, should be pulled through the entrance pit
- A final leak test should be performed on the installed pipe
- The contractor shall provide a set of as-built drawings including both alignment and profile. Drawing should be constructed from actual field reading. Raw data should be available for submission at any time upon owner request. As part of the 'As-Built' document the contractor should specify the tracking equipment used, including methods or confirmatory procedure used to ensure the data was captured

GLOSSARY

Closing this chapter is a glossary of terms that are pertinent, and often specific to the application of horizontal directional drilling.

annuls: In drilling, the annulus refers to the place that surrounds the drill pipe and is enclosed by the borehole wall.

API: American Petroleum Institute.

ASTM: American Society for Testing and Materials.

azimuth: Horizontal direction expressed as an angle measured clockwise from any meridian. In drilling, azimuths are typically measured from magnetic north.

Barite: Natural barium sulfate used for increasing the density of drilling fluids.

barrel reamer: An enclosed cylindrical soft soil reaming tool with cutting teeth and fluid nozzles arrayed on the end faces. Barrel reamers may be designed with specific buoyancies to aid in borehole enlargement.

bedding plane: Any of the division planes that separate the individual strata or depositional layers in sedimentary or stratified rock.

bent sub: A short threaded piece of pipe manufactured with an axial offset or angel. In directional drilling, a bent sub is used to produce a leading edge asymmetry in a non-rotating directional drill string.

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bentonite: Colloidal clay, composed primarily of montmorillonite, that swells when wet. Because of its gel-forming properties, bentonite is a major component of drilling mud.

bentonite extenders: Group of polymers that can maintain or increase the viscosity of bentonite while flocculating other clay solids in the mud. With bentonite extenders, desired viscosity can often be maintained using only half the amount of bentonite that would otherwise be required.

Bottom Hole Assembly (BHA): The combination of bit, downhole motor, subs, survey probe, and non magnetic collars assembled at the leading edge of a drill string.

boulder: Particle of rock that will not pass through a 12-inch square opening.

breakover: The over bend required to change the vertical orientation of a pipeline without inducing plastic deformation or unacceptable flexural stresses in the pipe.

bullet nose: An enclosed cylindrical soft soil reaming tool similar to a barrel reamer but with minimal cutting teeth and fluid nozzles. A bullet nose functions more as a centralized, expander, and fluid discharge point than a cutting tool and is typically used during pull back.

buoyancy control: The act of modifying the unit weight of a pipeline to achieve desired buoyancy. In HDD installation, this may be accomplished by placing water in the pipe during pull back.

Carboxymethyl Cellulose (CMC): A non-fermenting cellulose product used in drilling fluids to lower the water loss of the mud and produce viscosity.

carriage: Component of a horizontal drilling rig that travels along the frame and rotates the drill pipe. It is analogous to a top drive swivel on a vertical drilling rig.

centrifuge: Device used for the mechanical rotation to impart a centrifuge force to the fluid and achieve separation.

clay: Soil made up of particles passing a No. 200 U.S. standard sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents. Clay exhibits considerable strength when air dry.

cobble: Particle of rock that will pass through a 12 inch square opening and be retained on a 3 inch U.S. standard sieve.

density: The mass or weight of a substance per unit volume. For instance, the density of a drilling mud may be 10 pounds per gallon or 74.8 pounds per cubic foot.

desander: Centrifugal device (hydrocyclone) for removing sand from drilling fluid. Desanders are hydrocyclones larger than 5-inches in diameter.

desilter: Centrifugal device (hydrocyclone) for removing very fine particles, or silt, from drilling fluid. Desilters are hydrocyclones typically 4 or 5-inches in diameter.

diamond bit: Drilling bit that has a steel body surfaced with industrial diamonds, i.e. Polycrystalline Diamond Compact (PDC) bit.

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downhole motor: Device that uses hydraulic energy contained in a drilling fluid flow stream to achieve mechanical bit rotation.

downhole survey probe: Device containing instruments that read inclination, azimuth, and tool face. A downhole survey probe is placed at the leading of a directional drill string and provides data that the drill uses to steer the string.

entry point: The point on a drilled segment where the pilot hole bit initially penetrates the surface. The horizontal drilling rig is positioned at the entry point.

exit point: The point on a drill segment where the pilot hole bit finally penetrates the surface. The pipeline pull section is positioned at the exit point.

filter cake: Layer of concentrated solids from the drilling mud or cement slurry that forms on the walls of the borehole opposite permeable formations; also called wall cake or mud cake.

filtration: The process of separating solids from liquid by forcing the liquid through a porous medium.

flocculation: The coagulation of solids in a drilling fluid, produced by special additives or by contaminants.

fluid: Substance that will flow and readily assumes the shape of the container in which it is placed. The term includes both liquids and gases.

fluid loss: Measure of the relative amount of fluid lost by filtration of the drilling fluid into a permeable formation.

flycutter: Open circular, cylindrical, or radial blade soft soil reaming tool with cutting teeth and fluid nozzles arrayed on the circumference and blades.

fracture zone: Zone of naturally occurring fissures or fractures that can pose problems with lost circulation.

frame: Component of a horizontal drilling rig on which the carriage travels. It is generally set at an angle of 6 degrees to 20 degrees from horizontal. It is analogous to the mast on a vertical drilling rig.

gel: Semi-solid, jelly state assumed by some colloidal dispersions at rest. When agitated, the gel converts to a fluid state. Gel is also used as a name for bentonite.

gel strength: Measure of the ability of a colloidal dispersion to develop and retain a gel form, based on its resistance to shear. The gel strength, or shear strength, of a drilling mud determines its ability to hold solids in suspension. Sometimes bentonite and other colloidal clays are added to drilling fluid to increase its gel strength.

gravel: Particles of rock that will pass a 3-inch sieve and be retained on a No. 4 U.S. standard sieve.

hole opener: A rock reaming tool utilizing roller cutters to cut harder material than be penetrated with a flycutter.

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hole sizing: The act of moving a bit or reamer along a drilled hole one or more times to insure that the hole is open and annular drilling fluid flow can take place.

Horizontal Directional Drilling (HDD): A two-phase trench-less excavation method for installing buried pipelines and conduits. The first phase consists of drilling a directionally controlled pilot hole along a predetermined path grade at one end of a drilled segment to grade at the opposite end. The second phase consists of enlarging the pilot hole to a size, which will accommodate a pipeline or conduit, and pulling the pipeline or conduit into the enlarged hole. The method is accomplished using a horizontal drilling rig.

hydrocyclone: Conical device which directs drilling fluid flow in a spiraling manner thereby setting up centrifugal forces which aid in separating solids from the fluid. Hydrocyclones are also referred to as cyclones or cones.

hydrostatic head: Hydrostatic pressure.

hydrostatic pressure: The force exerted by a body of fluid at rest; it increases directly with the density and the depth of the fluid and is expressed in psi. The hydrostatic pressure of fresh water is 0.433 psi per foot of depth. In drilling, the term refers to the pressure exerted by the drilling fluid in the well bore.

inadvertent return: Uncontrolled flow of drilling fluid to the surface at locations other than the entry or exit points.

inclination: Angular deviation from true vertical or horizontal. In drilling, inclination is typically measured from vertical.

jetting: Advancing a drilled hole by using the hydraulic cutting action generated when drilling fluid is exhausted at high velocity through the leading edge of a drill string.

laminar flow: Flow in which fluid elements move along fixed streamlines which are parallel to the walls of the channel of flow.

LCM: Lost circulation material.

lost circulation: The quantities of whole mud lost to a formation, usually in cavernous, fissured, or coarsely permeable beds, evidenced by the complete or partial failure of the mud to return to the surface as it is being circulated in the hole; also called lost returns.

low clay solids mud: Heavily weighted mud whose high solids content (as a result of the large amounts of barite added) necessitates the reduction of clay solids.

low-solids mud: A drilling mud that contains minimum amount of soil material (sand, silt, etc.) and is used in rotary drilling when possible because it can provide fast drilling rates.

lubricity: The capacity of a fluid to reduce friction.

marsh funnel: A calibrated funnel used in field tests to indicate the viscosity of drilling mud.

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metastable structure: Soil structure that is stable only because of the existence of some supplementary influence. Sand simultaneously with silt may exhibit a metastable structure due to the silt particles interfering with the intergranular contact between the sand particles. A shock or sudden loading may cause the structure to break down and liquefy.

montmorillonite: Clay mineral often used as an additive to drilling mud. It is a hydrous aluminum silicate capable of reacting with such substances as magnesium and calcium.

mud: The liquid circulated through the well bore during rotary drilling operations. Although it was originally a suspension of earth solids (especially clays) in water, the mud used in modern drilling is a more complex, three-phase mixture of liquids, reactive solids, and inert solids. The liquid phase may be fresh water, diesel oil, or crude oil and may contain one or more conditioners.

mud balance: Instrument consisting of a cup and a graduated arm with a sliding weight and rest on a fulcrum. It is used to measure the unit weight of the mud.

mud cleaner: Item of equipment combining vibratory screens and hydrocyclones to achieve effective solids control.

mud-up: To add solid materials (such as bentonite or other clay) to a drilling fluid composed mainly of clear water to obtain certain desirable properties.

Newtonian fluid: The basic and simplest fluid (from the standpoint of viscosity consideration) in which the shear stress is directly proportional to the shear rate. These fluids will immediately begin to flow when pressure or force in excess of zero is applied.

non-Newtonian fluid: Fluid in which the shear force is not directly proportional to the shear rate. Non-Newtonian fluids do not have a constant viscosity.

organic clay: Clay with sufficient organic content to influence the soil properties.

organic silt: Silt with sufficient organic content to influence the soil properties.

over bend: Vertical bends in a pipeline which progresses downward.

peat: Soil composed of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

pilot hole: Small diameter hole directionally drilled along path in advance of reaming operations and pipe installation.

plastic: Capable of being shaped or formed; pliable.

plasticity index: Numerical difference between the liquid limit and the plastic limit of a soil.

plastic limit: The water content at which a soil begins to break apart and crumble when rolled into threads ⅛ inch in diameter.

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plastic viscosity: Absolute flow property indicating the flow resistance of certain types of fluids. Plastic viscosity is a measure of shearing stress.

plunger effect: The sudden increase in borehole pressure brought about by the rapid movement of a larger pipe or cutting tool along a drilled or reamed hole.

polyanionic cellulose: Chemical compound used to reduce water loss in mud that are affected by salt contamination.

polymer: Substance that consists of large molecules formed from smaller molecules in repeating structural units. In petroleum refining, heat and pressure are used to polymerize light hydrocarbons into larger molecules, such as those that make up high-octane gasoline. In drilling operations, various types of organic polymers are used to thicken drilling mud, fracturing fluid, acid, and other liquids. In petrochemical production, polymer hydrocarbons are used as the basis for plastics.

polymer mud: A drilling mud to which has been added a polymer, a chemical that consists of larger molecules that were formed from small molecules in repeating structural units, to increase the viscosity of the mud.

preream: The act of enlarging a pilot hole by pulling or pushing cutting tools along the hole prior to commencing pipe installation.

pull back: The act of installing a pipeline along a horizontally drilled hole by pulling it to the drilling rig from the end of the hole opposite the drilling rig.

pull back swivel: Device placed between the rotating drill string and tools and the pipeline pull section to minimize torsion transmitted to the section during pull back installation.

pull section: String of pipeline prefabricated at an adjacent location prior to being pulled into its final position.

rock: Any indurated material that requires drilling, wedging, blasting, or other methods of brute force for excavation.

roller cone bit: Drilling bit made of two, three, or four cones, or cutters, that are mounted on extremely rugged bearings. The surface of each cone is made of rows of steel teeth or tungsten carbide inserts.

rotational viscometer: Instrument used for assessing mud properties, returning values for both plastic viscosity and yield point.

Rock Quality Designation (RQD): An indication of the fractured nature of rock determined by summing the total length of core recovered counting only those pieces which are 4 inches or more in length and which are hard and sound. RQD is expressed as a percentage of the total core run.

sag bend: Vertical bends in a pipeline which progresses upward.

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sand: Particles of rock that will pass a No. 4 U.S. standard sieve and be retained on a No. 200 U.S. standard sieve.

shale shaker: Device that utilizes vibrating screens to remove larger solid particles from circulating drilling fluid. The fluid passes through the screen openings while solids are retained and moved off of the shaker by the vibrating motion.

side bend: Horizontal bend in a pipeline.

silt: Soil passing a No. 200 U.S. standard sieve that is non-plastic or very slightly plastic and that exhibits little or no strength when air dry.

slickenside: A smooth surface produced in rock or clay by movement along a fault or joint.

soil: Any unconsolidated material composed of discrete solid particles with gases or liquids between.

spoil: Excavated soil or rock.

Standard Penetration Test (SPT): An indication of the density or consistency of soils given by counting the number of blows required to drive a 2 inch OD split spoon sampler 12 inches using a 140 pound hammer falling 30 inches. The sampler is driven in three 6 inch increments. The sum of the blows required for the last two increments is referred to as the "N" value, blow count, or Standard Penetration Resistance.

spud in: To begin drilling; to start the hole.

sub: Short threaded piece of pipe used in a drill string to perform a special function.

surfactant: Substance that affects the properties of the surface of a liquid or solid by concentrating on the surface layer. Surfactants are useful in that their use can ensure that the surface of one substance or object is in thorough contact with the surface of another substance.

suspension: Mixture of small non setting particles of solid material within a gaseous or liquid medium.

swabbing effect: Phenomenon characterized by formation fluids being pulled or swabbed into the well bore when the drill stem and bit are pulled up the well bore fast enough to reduce the hydrostatic pressure of the mud below the bit.

tool face: Direction of the asymmetry of a drilling string. A directional drilling string will progress in the direction of the tool face. Tool face is normally expressed as a angle measured clockwise from the top of the drill pipe in a plane perpendicular to the axis of the drill pipe.

transition velocity: Velocity at which the flow in a particular fluid flowing in a particular channel shifts between laminar and turbulent.

trip: Act of withdrawing (tripping out) or inserting (tripping in) the drill string.

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turbulent flow: Fluid flow in which the velocity at a given point changes constantly in magnitude and direction.

twist off: To part or split drill pipe or drill collars, primarily because of metal fatigue in the pipe or because of mishandling.

velocity: Rate of linear motion per unit of time.

vices: Devices mounted on the frame of a horizontal drilling rig which grip the drill pipe and allow it to be made up (screwed together) or broken (unscrewed).

viscometer: Apparatus to determine the viscosity of a fluid.

viscosity: Measure of the resistance of a liquid flow. The internal friction resulting from the combined effects of cohesion and adhesion bring about resistance.

wall cake: Solid material deposited along the wall of a drilled hole resulting from filtration of the fluid part of the mud into the formation.

wash pipe: Drill pipe that is run, or rotated, concentrically over a smaller drill pipe so that the smaller (internal) pipe can be freely moved or rotated.

water-back: To reduce the weight or density of a drilling mud by adding water or to reduce the solids content of a mud by adding water.

weight-up: To increase the weight or density of drilling by adding weighting material.

yield point: Maximum stress that a solid can withstand without undergoing permanent deformation either by plastic flow or by rupture.

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CHAPTER 9
CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Chemical Resistance of Plastics and Elastomers Used in Pipeline Construction

1. Introduction

It is now inconceivable to construct pipelines without the use of plastics. Pipes made from plastics are used not only for drinking water, water for general use and waste water, but also for the conveyance of aggressive liquids and gases. Expensive pipe materials such as lined metal, ceramic or glass, have been largely superseded by plastic pipes. It is, however, important that the most suitable plastic material is selected for each application. This "Chemical Resistance List" serves as a useful guide in this respect. The list is periodically revised to include the latest findings. It contains all plastics and elastomers in the George Fischer product range which can come into direct contact with the media.

The information is based on experiments, immersion and, when available, on data from tests which include temperature and pressure as stress factors. The results achieved in immersion experiments cannot be applied without reservation to pipes under stress, i.e. internal pressure, as the factor "stress corrosion cracking" is not taken into consideration. In certain cases it can be of advantage to test the suitability under the planned working conditions. The tests referred to have been carried out partly by George Fischer and partly by the International Standardization Organization (ISO) or national standards organizations.

Pure chemicals were used for the tests. If a mixture of chemicals is to be conveyed in practice this may affect the chemical resistance of the plastic. It is possible in special cases to carry out appropriate tests with the specific mixture. Suitable test equipment is available at George Fischer for this purpose, which we regard as part of our service to the customer. It goes without saying that we are willing to give individual advice at any time. In this connection it is worth mentioning that George Fischer already possesses information concerning the behavior towards plastics of a number of chemicals or mixtures of chemicals which are not yet included in this list. The "Chemical Resistance List" gives valuable assistance in the planning of plastic pipelines. Please refer to the following instructions, which are important for the application and evaluation of this list.

2. Instructions for the Use of the Chemical Resistance List

2.1 General

As stated in the introduction, the "Chemical Resistance List" is only intended as a guide. Changes in the composition of the medium or special working conditions could lead to deviations. If there is any doubt, it is advisable to test the behavior of the material under the specific working conditions, by means of a pilot installation. No guarantees can be given in respect of the information contained in this booklet. The data shown is based upon information available at the time of printing, but it may, however, be revised from time to time in the light of subsequent research and experience.

2.2 Classification

The customary classifications: **resistant, conditionally resistant** and **not recommended** are depicted by the signs: +, O, and –, which allow simple presentation and application. These classifications are defined as:

Resistant: +
Within the acceptable limits of pressure and temperature the material is unaffected or only insignificantly affected.

Conditionally Resistant: O
The medium can attack the material or cause swelling. Restrictions must be made in regard to pressure and/or temperature, taking the expected service life into account. The service life of the installation can be noticeably shortened. Further consultation with George Fischer is recommended.

Not recommended: –
The material cannot be used with the medium at all, or only under special conditions.

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

2.3 Pipe Joints

2.3.1 Solvent Cement Joints (PVC)

Solvent cement joints made with standard PVC cement and primer systems are generally as resistant as the PVC material itself. The following chemicals are, however, an exception:

- Sulphuric acid H_2SO_4 in concentrations above 70 percent
- Hydrochloric acid HCl in concentrations above 25 percent
- Nitric acid HNO_3 in concentrations above 20 percent

Hydrofluoric acid in any concentration
In conjunction with the above media the solvent cement joining is classified as "conditionally resistant". Previously recommended solvent cement (Dytex, by Henkel, Germany) used for pipe and fittings to carry concentrated acids, can no longer be brought into the United States because of its methylene chloride solvent system being classified as a carcinogen. There is no known domestically available substitute. Special consideration should be given to the possible attack of the cemented joints by these concentrated acids.

2.3.2 Fusion Joints

In the case of PE, PP, and PVDF (SYGEF®) heat fusion joints have practically the same chemical resistance as the respective material. In conjunction with media which could cause stress cracking, the fused joints can be subjected to an increased risk due to residual stress from the joining process.

2.4 Sealing Materials

Depending upon the working conditions and the stress involved, the life span of the sealing materials can differ from that of the pipeline material. Seals in PTFE, which are not included in this list, are resistant to all the chemicals indicated. The greater permeability of PTFE should, however, be considered. Under certain working conditions, for example when conveying highly aggressive media such as hydrochloric acid, this material characteristic must be taken into account.

2.5 General Summary and Limits of Application

The following table includes all the materials contained in the George Fischer product range, and their abbreviations. The summary gives preliminary information regarding the general behavior of the materials and the temperature limits.

2.6 Standards

This list has been compiled with reference to the following ISO standards:
ISO/TR 7473
Unplasticized polyvinyl chloride pipes and fittings – Chemical resistance with respect to fluids.
ISO/TR 7474
High density polyethylene pipes and fittings – Chemical resistance with respect to fluids to be conveyed.
ISO/TR 7471
Polypropylene (PP) pipes and fittings – Chemical resistance with respect to fluids.
ISO TR 10358
Plastic pipes and fittings – Combined chemical resistance classification table.
DVS 2205 Part 1
Calculations for thermoplastic containers and appliances.
DIN 8080 Supplement 1 «Pipes of chlorinated polyvinyl chloride (PVC-C), PVC-C 250 – Chemical Resistance».

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Material	Abbreviation	Remarks	Maximum Permissible Temperature (Water) °C	
			Constant	Short Term
Polyvinyl Chloride	PVC	Resistant to most solutions of acids, alkalis and salts and to organic compounds miscible with water. Not resistant to aromatic and chlorinated hydrocarbons	60°	60°
Chlorinated Polyvinyl Chloride	CPVC	Can be used similarly to PVC but at higher temperatures. Consult factory for specific applications.	90°	110°
High-density Polyethylene	PE 50	Resistant to hydrous solutions of acids, alkalis and salts as well as to a large number of organic solvents. Unsuitable for concentrated oxidizing acids.	60°	80°
Polypropylene, heat stabilized	PP	Chemical resistance similar to that of PE but suitable for higher temperatures	90°	110°
Polyvinylidene Fluoride	PVDF (SYGEF®)	Resistant to acids, solutions of salts, aliphatic, aromatic and chlorinated hydrocarbons, alcohols and halogens. Conditionally suitable for ketones, esters, organic bases and alkaline solutions	140°	150°
Polybutylene-1	PB	Similar to PE 50, but can be used up to 90°C	90°	100°
Polyoxymethylene	POM	Resistant to most solvents and hydrous alkalis. Unsuitable for acids	60°	80°
Polytetrafluoroethylene (e.g. Teflon®)	PTFE	Resistant to all chemicals in this list	250°	300°
Nitrile Rubber	NBR	Good resistance to oil and petrol. Unsuitable for oxidizing media	90°	120°
Buty Rubber Ethylene Propylene Rubber	IIR EPDM	Good resistance to ozone and weather. Especially suitable for aggressive chemicals. Unsuitable for oils and fats	90°	120°
Chloroprene Rubber (e.g. Neoprene®)	CR	Chemical resistance very similar to that of PVC-U and between that of Nitrile and Buty Rubber	80°	110°
Fluorine Rubber (e.g. Viton®)	FPM	Has best chemical resistance to solvents of all elastomers	150°	200°
Chlorine Sulphonyl Polyethylene (e.g. Hypalon®)	CSM	Chemical resistance similar to that of EPDM	100°	140°

®Registered trade name

The abbreviations listed below are found throughout the listings and have the following definition:

Q/E (Quellung/Erweichung) = swelling/softening
D/P (Diffusion/Permeation) = diffusion/permeation
SpRB (Spannungsrissbildung) = environmental stress cracking

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Acetaldehyde	CH_3·CHO (C_2H_4O)	21	technically pure	20 40 60 80 100 120 140	- 	- 	- 	+ ○ 	○ - 	- 		+ ○ - 	○ - 	- 	- 	○ -
Acetaldehyde			40%, aqueous solution	20 40 60 80 100 120 140	○ - 	- 	- 	+ + ○ 	+ + + ○ - 	- 		+ + + + 	+ + ○ - 	- 	+ + ○ - 	+ + + +
Acetic acid (SpRB)	CH_3COOH	118	technically pure, glacial	20 40 60 80 100 120 140	○ - 	- 	- 	+ + ○ 	+ + ○ - 	+ ○ - 		○ 	- 	- 	○ 	○
Acetic acid (SpRB)	CH_3COOH		10%, aqueous	20 40 60 80 100 120 140	+ + ○ 	+ + + + 	+ + ○ 	+ + + 	+ + + + + 	+ + + + + + 		+ + ○ 	○ - 	+ ○ 	+ + ○ 	○ -
Acetic acid (SpRB)			50%, aqueous	20 40 60 80 100 120 140	+ + ○ 	+ 	- 	+ + + 	+ + + ○ 	+ + + ○ 		+ 	○ 	- 	○ 	○
Acetic acid (SpRB)	CH_3COOH		60%	20 40 60 80 100 120 140	+ 	- 	- 	+ 	+ 	+ 		+ 				
Acetic acid (SpRB)		118	98%	20 40 60 80 100 120 140	- 	- 	- 	+ 	+ 	+ 		○ 	- 			
Acetic acid anhydride (SpRB)	$(CH_3CO)_2O$	139	technically pure	20 40 60 80 100 120 140	- 	- 	- 	+ ○ 	+ ○ 	- 		○ 	- 	- 	- 	+

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Acetic acid isobutyl ester	$(CH_2)_2$-CH-$(CH_2)_2$-CO_2H		technically pure	20						-						
				40												
				60												
				80												
				100												
				120												
				140												
Acetone	CH_3-CO-CH_3	56	technically pure	20	-	-	-	+	+	-		+	-	-	-	O
				40				+	+			+				O
				60				+	+			+				O
				80												
				100												
				120												
				140												
Acetone			up to 10%, aqueous	20	-	-	O	+	+	O		+	O	-	+	O
				40				+	+	O		+	O		O	O
				60				+	+	O		+	-		-	O
				80												
				100												
				120												
				140												
Acetonitrile	CH_3CN	81.6	100%	20	-	-	-			-						
				40												
				60												
				80												
				100												
				120												
				140												
Acetophenone	CH_3-CO-C_6H_5		100 %	20	-	-	-			-		+	-	-	-	
				40												
				60												
				80												
				100												
				120												
				140												
Acrylic acid methyl ester	CH_2=CHCOOCH_3	80.3	technically pure	20	-	-	-			+		O				
				40												
				60												
				80												
				100												
				120												
				140												
Acrylic ester	CH_2=CH-COO CH_2CH_3	100	technically pure	20	-	-	-		-	-		O	-	-	O	+
				40												
				60												
				80												
				100												
				120												
				140												
Acrylonitrile	CH_2=CH-CN	77	technically pure	20	-	-	-	+	+	-		+	O	-	+	O
				40				+	O			+	O		+	O
				60				+				O	-		+	
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Adipic acid	$HOOC-(CH_2)_4-COOH$	Fp 153	saturated, aqueous	20	+	+	-	+	+	+		+	+	+	+	+
				40	+	+		+	+			+	+	+	+	+
				60	-	+		+	+			+	+	+	+	+
				80		+			+							
				100												
				120												
				140												
Aluni	see Potassium/ aluminium sulphate															
Alcoholic spirits (Gin, Whisky,etc.)			approx. 40% ethyl alcohol	20	+	O	-	+	+	+		+	+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Allyl alcohol	$H_2C=CH-CH_2-OH$	97	96%	20	O	O	-	+	+			O	O	+	O	+
				40	-			+	+			O	-	+	-	+
				60				+	+			O		+		+
				80								-		+		-
				100												
				120												
				140												
Aluminium chloride	$AlCl_3$		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	O	+	+
				80		+	+			+		+	+			+
				100			+			+		+	+			
				120			+									
				140												
Aluminium chloride	$AlCl_2$	115	saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+	+		+	+			+	O	+	+
				100					O	+			+	-		+
				120						+						
				140												
Aluminium fluoride	AlF_3		saturated	20		+				+						
				40		+				+						
				60		+				+						
				80						+						
				100												
				120												
				140												
Aluminium hydroxide	$Al(OH)_3$		Suspension	20		+						+				
				40		+						+				
				60		+						+				
				80		+										
				100												
				120												
				140												
Aluminium nitrate	$Al(NO_3)_3$		saturated	20		+				+		+				
				40		+				+		+				
				60		+				+		+				
				80		+										
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF ISYGEF1		EPDM	FPM	NBR	CR	CSM
Aluminium sulphate	$Al_2(SO_4)_3$		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	○	+	+	+	+	+		+	+	+	+	+
				80		+			+	+			+			○
				100					+	+						
				120						+						
				140												
Aluminium sulphate			cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	○
				80		+			+	+			+			○
				100						+						
				120						+						
				140												
Ammonia (SpRBI	NH_3	-33	gaseous, technically pure	20	+	-	-	+	+	+		+	+	+	+	+
				40	+			+	+	+			○			
				60	+			+	+	○						
				80						○						
				100						○						
				120												
				140												
Ammonium acetate	CH_3COONH_4		aqueous, all	20	+	+	○	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	○	+	+
				60	○	+		+	+	+		+	+		○	
				80		+			+	+		○	+			
				100					+	+						
				120												
				140												
Ammonium aluminium sulfate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium bromide				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Ammonium carbonate	$(NH_4)_2CO_3$		50%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	○	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100						+						
				120												
				140												
Ammonium chloride	NH_4Cl	115	aqueous, cold saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	○	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100					+	+						
				120						+						
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ammonium citrate				20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Ammonium dicromate	$(NH_4)_2 Cr_2 O_7$		saturated	20		+										
				40		+										
				60		+										
				80		+										
				100												
				120												
				140												
Ammonium dihydrogenphosphate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Ammonium fluoride	NH_4F			20	+	+		+	+	+						
				40	+			+	+	+						
				60	+			+	+	+						
				80					+	+						
				100						+						
				120												
				140												
Ammonium formiate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium hexafluorosilicate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium hydrogen fluoride	NH_4HF_2		50%, aqueous	20	+	+	-	+	+	+		+	+			
				40	+	+		+	+	+						
				60	O	+		+	+	+						
				80												
				100												
				120												
				140												
Ammonium hydrogencarbonate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF ISYGEFI		EPDM	FPM	NBR	CR	CSM
Ammonium hydrogenphosphate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Ammonium hydrogensulfite				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium hydroxide	NH_4OH		aqueous, cold	20	+	-	+		+	-		+	-		+	+
			saturated	40	+		+		+			+		O	+	+
				60	O		O		+			O		O	+	O
				80											O	-
				100												
				120												
				140												
Ammonium nitrate	NH_4NO_3	112	aqueous, saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+		+
				60	+	+	+	O	+	+		+	+	O		O
				80		+			O	+			+			
				100						+						
				120						+						
				140												
Ammonium oxalate	$H_4NOOC\text{-}COONH_4$			20						+		+				
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium persulphate	$(NH_4)_2S_2O_8$			20		+				+						
				40		+				+						
				60		+				+						
				80		+				+						
				100						+						
				120												
				140												
Ammonium phosphate	$(NH_4)_3PO_4$		saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+			+	O	+	O
				80						+			+			
				100						+						
				120												
				140												
Ammonium sulphate	$(NH_4)_2SO_4$		aqueous, saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	O	+	O
				80		+			+	+		+	+			
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ammonium sulphide	$(NH_4)_2S$		aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	○	+	+	+
				60	○	○	+	+	+	+		+	-	+	+	+
				80		-			+	+						+
				100												
				120												
				140												
Ammonium tetrafluoroborcte				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium thiocyanate	NH_4SCN		saturated	20		+				+						
				40		+				+						
				60		+				+						
				80		+										
				100												
				120												
				140												
Amyl acetate	$CH_3(CH_2)_4\text{-}COOCH_3$	141	technically pure	20	-	-	-	+	○	+		○	-	-	-	-
				40				+	○	○						
				60				+	-	○						
				80												
				100												
				120												
				140												
Amyl alcohol (SpRB)	$CH_3(CH_2)_3\text{-}CH_2\text{-}OH$	137	technically pure	20	+	+	-	+	+	+		+	○	+	+	○
				40	+	+		+	+	+		+		+	+	
				60	○	+		+	+	+		+		+	+	
				80					+	+						
				100						+						
				120						○						
				140												
Aniline	$C_6H_5NH_2$	182	technically pure	20	-	-	-	○	○	+		-	○	-	-	-
				40						○			○			
				60						-			○			
				80												
				100												
				120												
				140												
Aniline hydrochloride	$C_6H_7N{+}HCl$	245	aqueous, saturated	20	+	+	-	+	+	+		+	○	○	-	+
				40	○	+		+	+			+	-	-		+
				60				○	○			+				+
				80												○
				100												
				120												
				140												
Antimony thiocyanate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Antimony trichloride (SpRB)	$SbCl_3$		90%, aqueous	20	+	+	-	+	+	+		+	+	-	+	+
				40	+			+	+	+						
				60				+	+	+						
				80												
				100												
				120												
				140												
Aqua regia (SpRB)	HNO_3+HCl			20	+	+	-	-	-	O		-	O	-	-	O
				40	O											
				60												
				80												
				100												
				120												
				140												
Arsenic acid	H_3AsO_4		80%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+	O	+	+
				100						+			+			
				120						+						
				140												
Barium carbonate	$BaCO_3$			20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+			+	+		+	+	+		
				60	+	+			+	+		+				
				80		+			+							
				100												
				120												
				140												
Barium chloride	$BaCl_2$		saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+			+	+		+	+	+		
				60	+	+			+	+		+	+			
				80		+				+			+			
				100						+						
				120												
				140												
Barium hydroxide	$Ba(OH)_2$	102	aqueous, saturated	20	+	+	+	+	+	-		+	+	+	+	+
				40	+	+	+	+	+			+		+	+	O
				60	O	+	+	+	+			+		+	+	
				80		+			+			+				
				100												
				120												
				140												
Barium salts			aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+			
				100						+						
				120												
				140												
Barium sulfate	$BaSO_4$			20	+			+	+	+		+				
				40	+			+	+	+		+				
				60	+			+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF ISYGEFI		EPDM	FPM	NBR	CR	CSM
Barium sulfide	BaS		suspension	20	+	+		+	+	+		+				
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+						
				100						+						
				120												
				140												
Battery acid	see Sulphuric acid 40%															
Beef tallow emulsion, sulphonated (SpRB)			usual commercial	20	+	o	+	+	+	+		-	+	+	+	+
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Beer			usual commercial	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80		+				+						
				100												
				120												
				140												
Benzaldehyde	C_6H_5-CHO	180	saturated, aqueous	20	-	-	-	+	+	+		+	+	O	-	-
				40				+		O		+	+			
				60				+		-		+	+			
				80												
				100												
				120												
				140												
Benzene	C_6H_6	80	technically pure	20	-	-	-	O	O	+		-	+	O	-	-
				40				O	-	O						
				60						-						
				80												
				100												
				120												
				140												
Benzenesulfonic acid	$C_6H_5SO_3H$		technically pure	20						+			+			
				40						+			+			
				60						+						
				80						+						
				100						+						
				120												
				140												
Benzoic acid	C_6H_5-COOH	Fp.*, 122	aqueous, all	20	+	+	+	+	+	+		+	+	-	-	-
				40	+	+	+	+	+	+		+	+			
				60	O	+		+	+	+			+			
				80		O			+	+			+			
				100					+	+			O			
				120						+						
				140												
Benzoyl chloride	$C_6H_5CHCl_2$		technically pure	20						+						
				40						+						
				60						+						
				80						O						
				100						-						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Benzyl alcohol (SpRB)	C_6H_5-CH_2-OH	206	technically pure	20	O	-	-	+	+	+		-	+	-	+	O
				40				+	+	+					+	
				60				O	O	O					+	
				80						-						
				100												
				120												
				140												
Beryllium chloride				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Beryllium sulfate				20						+			+			
				40						+			+			
				60						+			+			
				80						+						
				100						+						
				120												
				140												
Borax	$Na_2B_4O_7$		aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	O
				80		+			+	+		+	+			
				100					+	+						
				120												
				140												
Boric acid	H_3BO_3		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+			
				100					+	+			+			
				120						+						
				140												
Brine, containing chlorine				20	+	+	-	+	O	+		O	+	O	O	O
				40	+	+				+						
				60	+	+				O						
				80												
				100												
				120												
				140												
Brombenzene	C_6H_5Br			20	-	-				+			+			
				40												
				60												
				80												
				100												
				120												
				140												
Bromine, liquid	Br_2	59	technically pure	20	-	-	-	-	-	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						O						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Bromine, vapours	Br_2		high	20	-	-	-	-	-	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						+						
				120						O						
				140												
Bromine water	$Br.H_2O$		saturated, aqueous	20	+	o	-	-	-	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Butadiene (Q/E)	$H_2C=CH-CH=CH_2$	-4	technically pure	20	+	+	-	+	+	+		-	O	-	+	+
				40					+	+					+	+
				60					+	+					O	-
				80						+						
				100						+						
				120												
				140												
Butane	C_4H_{10}	0	technically pure	20	+	+	+	+	+	+		-	+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Butanediol (SpRB)	$HO-(CH_2)_4-OH$	230	aqueous, 10%	20	+	+	-	+	+			+	+	+	O	+
				40	O	+		+	+			+	+	+	-	+
				60				+	+			+	+	+		+
				80												
				100												
				120												
				140												
Butanol (SpRB)	C_4H_9OH	117	technically pure	20	+	+	-	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	O	+	+	+
				60	O	+		+	O	+		+	-	+	O	+
				80		O			-	+						
				100						O						
				120												
				140												
Butyl acetate	$CH_3COOCH_2CH_2CH_2CH_3$	126	technically pure	20	-	-	-	+	O	+		+	O	-	O	O
				40						O		-	-		-	-
				60						-						
				80												
				100												
				120												
				140												
Butyl phenol, p-tertiary	$(CH_3)_3C-C_6H_4-OH$	237	technically pure	20	O	O	-	O	+	+		-	O	-	-	-
				40	-	-				+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Butylene glycol (SpRB)	$HO\text{-}CH_2\text{-}CH{=}CH\text{-}CH_2\text{-}OH$	235	technically pure	20	+	+	+	+	+	+	+	+	-	+	O
				40	+	+	+	+	+	+	+	+		+	-
				60	O	+	+	+	+	+	+	O		+	
				80						+					
				100											
				120											
				140											
Butylene liquid	C_4H_8	51	technically pure	20	+			-	-	+	O	+	+	+	O
				40											
				60											
				80											
				100											
				120											
				140											
Butyric acid (SpRB)	$CH_3\text{-}CH_2\text{-}CH_2\text{-}COOH$	163	technically pure	20	+	+	-	+	+	+	O	O	-	O	O
				40				+		+					
				60				O		+					
				80						+					
				100						O					
				120											
				140											
Cadmium bromide	$CdBr_2$			20	+	+		+	+		+	+			
				40	+	+		+	+		+	+			
				60	+	+		+	+		+	+			
				80		+						+			
				100											
				120											
				140											
Cadmium chloride	$CdCl_2$			20	+	+		+	+		+	+			
				40	+	+		+	+		+	+			
				60	+	+		+	+		+	+			
				80					+						
				100											
				120											
				140											
Cadmium cyanide	CdICNI2			20	+			+	+						
				40	+			+	+						
				60	+			+	+						
				80					+						
				100											
				120											
				140											
Cadmium sulfate	$CdSO_4$			20	+	+		+	+		+	+			
				40	+	+		+	+		+	+			
				60	+	+		+	+		+	+			
				80		+			+			+			
				100											
				120											
				140											
Calcium acetate	$(CH_5COO)_2Ca$		saturated	20	+	+	+	+	+	+	+	+			
				40	+	+		+	+	+	+				
				60		+		+	+	+	+				
				80		+									
				100											
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF ISYGEF		EPDM	FPM	NBR	CR	CSM
Calcium bisulphite	$Ca(HSO_3)_2$		cold saturated, aqueous	20	+	+	+			+		+	+	-	O	+
				40		+	+			+			+			
				60		+				+			+			
				80		+				+			+			
				100						+						
				120						+						
				140												
Calcium carbonate	$CaCO_3$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+						
				120												
				140												
Calcium chlorate	$Ca(ClO_3)_2$			20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+										
				100												
				120												
				140												
Calcium chloride	$CaCl_2$	125	saturated, aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+	O	O	+
				100					+	+		O	+			+
				120						+						
				140												
Calcium fluoride	CaF_2			20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Calcium hydrogencarbonate				20						+		+	+			
				40						+		+	+			
				60						+		+	+			
				80						+		+	+			
				100						+			+			
				120												
				140												
Calcium hydrogensulfide	$Ca(SH)_2$			20		+				+		+				
				40		+				+		+				
				60		+				+		+				
				80		+				+						
				100						+						
				120												
				140												
Calcium hydrosulfite	$Ca(HSO_3)_2$		saturated	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF ISYGEFI		EPDM	FPM	NBR	CR	CSM
Calcium hydroxide	$Ca(OH)_2$	100	saturated, aqueous	20	+	+	+	+	+	O		+	+	+	+	+
				40	+	+	+	+	+	-		+	+	+	+	+
				60	+	+	+	+	+			+	+	O		+
				80		+			+			+	+			+
				100									+			+
				120												
				140												
Calcium nitrate	$Ca(NO_3)_2$	115	50%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60		+			+	+		+	+			+
				80		+				+			+			
				100						+						
				120												
				140												
Calcium phosphate	$Ca(H_2PO_4)_2$ $CaHPO_4$ $Ca_3(PO_4)_2$			20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Calcium sulfide	Ca_5			20	+				+			+				
				40	+				+							
				60	+				+							
				80					+							
				100												
				120												
				140												
Calcium sulphate	$CaSO_4$		suspensions	20	+	+				+		+				
				40	+	+				+		+				
				60	+	+				+		+				
				80		+				+						
				100						+						
				120												
				140												
Calcium sulphite	$Ca(HSO_3)_2$		aqueous, cold saturated	20	+			+	+			+				
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Calcium tungstate				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Calciumbromide	$CaBr_2$			20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+			
				80		+			+							
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF ISYGEFI		EPDM	FPM	NBR	CR	CSM
Calciumlactate	$(CH_3COO)_2Ca$		saturated	20				+	+	+		+				
				40				+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Caprolactam	$C_6H_{11}NO$			20		-										
				40												
				60												
				80												
				100												
				120												
				140												
Caprolactone	$C_6H_{10}O_2$			20		-										
				40												
				60												
				80												
				100												
				120												
				140												
Carbon dioxide -carbonic acid	CO_2		technically pure, anhydrous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+			+	+	+	+
				80		+			+	+			+			+
				100						+						
				120												
				140												
Carbon disulphide	CS_2	46	technically pure	20	-	-	-	O	O	+			+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Carbon tetrachloride	CCl_4	77	technically pure	20	-	-	-	-	-	+		-	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Carbonic acid				20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Caro's acid	see Peroxomonosulfuric acid															
Casein				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Cäsium chloride	ClCs			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Cäsiumhydroxide	CsOH			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Caustic potash solution (potassium hydroxide)	KOH	131	50%, aqueous	20	+	+	+	+	+	-		+	-	O	-	+
				40	+	+	+	+	+			+		-		O
				60	O	+	+	+	+			+				O
				80		+			+			O				-
				100					+							
				120												
				140												
Caustic soda solution	NaOH		50%, aqueous	20	+	+	+	+	+	O		+	-	O	-	+
				40	+	+	+	+	+			+		-		O
				60		+		+	+			+				-
				80					+							
				100												
				120												
				140												
Cerium (III) -chloride	$CeCl_3$			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Chloral hydrate	CCl_3-$CH(OH)_2$	98	technically pure	20	-		-	+	O	-		O	O	-	O	+
				40				+								
				60				+	-							
				80												
				100												
				120												
				140												
Chloric acid (SpRB)	$HClO_3$		10%, aqueous	20	+	+	-	+	-	+		+	-	-	-	+
				40	+	+		+		+		+				+
				60	O	+						+				+
				80												
				100												
				120												
				140												
Chloric acid (SpRB)	$HClO_3$		20%, aqueous	20	+	+	-	O	-	+		+	-	-	-	+
				40	+	+						+				+
				60	O	+										
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Chlorosulphonic acid	$ClSO_3H$	158	technically pure	20	O	-	-	-	-	O	-	-	-	-	-
				40						-					
				60											
				80											
				100											
				120											
				140											
Chrome alum (chromium potassium sulphate)	$KCr(SO_4)2$		cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+		+	+		+	+	+	+	+
				80							+	+			
				100								+			
				120											
				140											
Chromic acid (SpRB)	CrO_3+H_2O		up to 50%, aqueous	20	O	+	-	O	O	+	O	+	-	-	O
				40	O	O		-	-	+	O	+			O
				60	-	O				+	O	+			O
				80		-				+					
				100						O					
				120						O					
				140											
Chromic acid (SpRB)			all, aqueous	20	O	O	-	O	O	+		+	-	-	O
				40						+		+			O
				60						+		O			O
				80						O					
				100						O					
				120											
				140											
Chromic acid + sulphuric acid + water (SpRB)	CrO_3 H_2SO_4 H_2O		50 g 15 g 35 g	20	+	+	-	-	-	+	O	+	-	-	O
				40	+	+				+	O	+			O
				60	O	+				+		+			
				80		O				O					
				100											
				120											
				140											
Chromium (III) -chloride				20	+					+					
				40	+					+					
				60	+					+					
				80						+					
				100						+					
				120											
				140											
Chromium (III) -fluoride	CrF_3			20						+					
				40						+					
				60						+					
				80											
				100											
				120											
				140											
Chromium (III) -chloride	$CrCl_3$			20	+					+					
				40	+					+					
				60	+					+					
				80						+					
				100						+					
				120											
				140											

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Chlorine	Cl_2		moist, 97%, gaseous	20	-	-	-	-	-	-		-	+	-	-	O
				40												
				60												
				80												
				100												
				120												
				140												
Chlorine	Cl_2		anhydrous, technically pure	20	-	-	-	O	-	+		O	+	-	-	O
				40				O		+						
				60				-		+						
				80						+						
				100						O						
				120												
				140												
Chlorine	Cl_2		liquid, technically pure	20	-	-	-	-	-	+		-	O	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Chlorine water (SpRB)	Cl_2 H_2O		saturated	20	+	+	O	O	O	O		O	O	-	O	-
				40	+	+		O								
				60	O	O										
				80		-										
				100												
				120												
				140												
Chloroacetic acid, mono (SpRB)	$ClCH_2COOH$		50%, aqueous	20	+	-	-	+	+	+		O	-	-	-	O
				40	+			+	+	O						
				60				+	+	-						
				80												
				100												
				120												
				140												
Chloroacetic acid, mono (SpRB)	$ClCH_2COOH$	188	technically pure	20	+	-	-	+	+	-		O	-	-	-	O
				40	+			+	+							
				60	O			+	+							
				80												
				100												
				120												
				140												
Chlorobenzene	C_6H_5Cl	132	technically pure	20	-	-	-	O	+	+		-	-	-	-	O
				40						+						
				60						O						
				80						-						
				100												
				120												
				140												
Chloroethanol	$ClCH_2$-CH_2OH	129	technically pure	20	-		-	+	+	+		O	-	+	-	O
				40				+	+	O						
				60				+	+	O						
				80						-						
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Chromium (III) -nitrate	$CrNO_3I_3$			20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Chromium (III) -sulfate	$Cr_2ISO_4I_3$			20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Cider				20	+	+	+	+	+	+		+	+	+	+	+
				40			+			+						
				60						+						
				80												
				100												
				120												
				140												
Citric acid		Fp. *153	10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O		+	+	+	+		+	+	O	+	+
				80					+	+						
				100					+	+						
				120												
				140												
Citric acid				20	+			+	+							
				40	+			+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Citric acid up to 10 %				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Coal gas, benzene free				20	+	+	+	+	+	+			+	+	O	+
				40												
				60												
				80												
				100												
				120												
				140												
Coconut fat alcohol (SpRB)			technically pure	20	+	-	-	+	+	+			+	+	+	+
				40	+			O	+	+			+	+	O	O
				60	O				O	+			+	+		
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Compressedair, containing oil (SpRB)				20	-	-	-	+	○	+		-	+	+	+	+
				40				+		+						
				60						+						
				80												
				100												
				120												
				140												
Copper salts	$CuCl$, $CuCl_2$, CuF_2, $CuNO_3)_2$, $CuSO_4$, $Cu(CN)_2$		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	○	+	+	+	+	+			+	○	+	○
				80		+			+	+			+			
				100						+						
				120												
				140												
Corn oil (SpRB)			technically pure	20	○	○	○	+	+	+			+	+	○	+
				40		○		+	+	+			+	+	-	+
				60				○	○	+			+	+		○
				80						+						
				100												
				120												
				140												
Cresol	$HO-C_6H_4-CH_3$		cold saturated, aqueous	20	○	-	-	+	+	+			+	○	-	○
				40				+	+	+			+	○		
				60						+						
				80						○						
				100												
				120												
				140												
Crotonic aldehyde	$CH_3-CH=CH-CHO$	102	technically pure	20	-	-	-	+	+	+		+	+	+	+	+
				40						○						
				60						-						
				80												
				100												
				120												
				140												
Cyclohexane (Q/E)	C_6H_{12}	81	technically pure	20	-	-	-	+	+	+		-	+	+	-	-
				40				+		+						
				60				+		+						
				80						+						
				100												
				120												
				140												
Cyclohexanol (SpRB)	$C_6H_{12}O$	161	technically pure	20	+	+	-	+	+	+		-	+	○	+	+
				40	+	+		+	+	+						
				60	+	+		+	○	○						
				80		○				○						
				100						-						
				120												
				140												
Cyclohexanone	$C_6H_{10}O$	155	technically pure	20	-	-	-	+	+	+		○	-	-	-	-
				40				○	○	○						
				60				○	○	-						
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Densodrine W				20	+	+	○			+			+	+	+	
				40	+	+										
				60	+	+										
				80												
				100												
				120												
				140												
Detergents ISpRBI	see washing powder		for usual washing lathers													
Dextrine	$(C_6H_{10}O_5)_x$		usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+		+		+	+	+	+	+
				80		+				+						
				100						+						
				120						+						
				140												
Dextrose	siehe Glucose			20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Dibuttyl ether	$C_4H_9OC_4H_9$	142	technically pure	20	-	-	-	○	○			-	+	+	-	○ ○
				40									+	○		
				60				-	-				○	-		○ ○
				80												
				100												
				120												
				140												
Dibutyl phthalate	$C_6H_4(COOC_4H_9)_2$	340	technically pure	20	-	-	-	+	+	+		○	○	-	-	-
				40				○	○	+						
				60				○	○	○						
				80												
				100												
				120												
				140												
Dibutyl sebacate	$C_8H_{16}(COOC_4H_9)_2$	344	technically pure	20	-	-	-	+	+	+		+	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Dichlorbenzol	$C_6H_4Cl_2$	180	technically pure	20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Dichloroacetic acid	$Cl_2CHCOOH$	194	technically pure	20	+	-	-	+	+	+		+	○	-	○	+
				40	+			+	+	+		+	-		-	○
				60	○			○	○	○		+				-
				80						-						
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Dichloroacetic acid (SpRB)	$Cl_2CHCOOH$		50%, aqueous	20	+	-	-	+	+	+		+	O	-	O	+
				40	+			+	+	+		+	O	-	O	+
				60	O			+	+	+		+	-	-	-	+
				80						O						O
				100						-						
				120												
				140												
Dichloroacetic acid methyl ester	$Cl_2CHCOOCH_3$	143	technically pure	20	-	-	-	+	+	O		+	-	-	-	+
				40				+	+			+				+
				60				+	+			O				O
				80												
				100												
				120												
				140												
Dichloroethan	Ethylene chloride															
Dichloroethylene	ClCH=CHCl	60	technically pure	20	-	-	-	-	O	+		-	O	-	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Dichloromethane				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Diesel oil (SpRB, Q/E)				20	+	+	O	+	O	+		-	+	+	O	O
				40	+	+				+			+	+		-
				60				O		+						
				80						+						
				100						+						
				120						+						
				140												
Diethyl ether				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Diethylamine	$(C_2H_5)_2NH$	56	technically pure	20	O	-	-	+	+	+		O	-	-	-	-
				40						O						
				60						-						
				80												
				100												
				120												
				140												
Diethylene glycol butyl ether				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Diglycolic acid (SpRB)	$HOOC\text{-}CH_2\text{-}O\text{-}CH_2\text{-}COOH$	Fp*, 148	30%, aqueous	20	+	+	+	+	+	+		+	○	+	+	○
				40	+	+		+	+							
				60	○	+		+	+							
				80												
				100												
				120												
				140												
Di-isobutyl ketone	$[(CH_3)2CHCH_2)_2CO$	124	technically pure	20	-	-	-	+	+	+		○	-	-	-	-
				40						+						
				60				-	-	○						
				80												
				100												
				120												
				140												
Dimethyl formamide	$(CH_3)_2CHNO$	153	technically pure	20	-	-	-	+	+	-		○	-	○	+	+
				40				+	+							
				60				○	+							
				80												
				100												
				120												
				140												
Dimethylamine	$(CH_3)_2NH$	7	technically pure	20	○	-	-	+	+	○		○	-	-	-	-
				40						-						
				60				○								
				80												
				100												
				120												
				140												
Dimethylphthalate (DMP)	$C_6H_4(CH_3)_2$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Dinonylphthalate (DNP)			technically pure	20	-	-	-	○	+			○	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Dioctylephthalate (SpRB) (DOP)			technically pure	20	-	-	-	○	+			○	+	-	-	-
				40												
				60					-							
				80												
				100												
				120												
				140												
Dioxane	$C_4H_8O_2$	101	technically pure	20	-	-	-	+	○	-			-	○	-	-
				40				+	○							
				60				+	○							
				80					-							
				100												
				120												
				140												
Drinking water	see water															

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ethanolamine	see Annino ethanol															
Ethyl acetate	CH_3COOCH_2-CH_3	77	technically pure	20	-	-	-	+	+	○		+	-	-	-	-
				40				○ +	○							
				60				○	○							
				80												
				100												
				120												
				140												
Ethyl alcohol + acetic acid (fermentation mixture)			technically pure	20	+	○	-	+	+	+		○	○	○	+	+
				40	+			+		+		○	○	○	+	+
				60	○			+		+		○	○		+	+
				80						○						
				100												
				120												
				140												
Ethyl alcohol (Ethnol (SpRB)	CH_3-CH_2-OH	78	technically pure, 96%	20	+	○	-	+	+	+		+	○	○	+	+
				40	+			+	+	○		+	○			
				60	○			+	+	-		+	○			
				80					+							
				100												
				120												
				140												
Ethyl benzene	C_6H_5-CH_2CH_3	136	technically pure	20	-	-	-	○	○	○		-	+	-	-	
				40					-							
				60												
				80												
				100												
				120												
				140												
Ethyl chloride	CH_3-CH_2Cl	12	technically pure	20	-	-	-	○	○	○		-	○	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Ethyl ether	CH_3CH_2-O-CH_2CH_3	35	technically pure	20	-	-	-	+	○	+		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Ethylenchloride (1,2-Dichloroethane)				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Ethylene chloride	$ClCH_2$-CH_2Cl	83	technically pure	20	-	-	-	○	○	+		-	+	○	○	-
				40						+			+	-	-	
				60						+			○			
				80						○						
				100						-						
				120												
				140												

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Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ethylene diamine	$H_2N\text{-}CH_2\text{-}CH_2\text{-}NH_2$	117	technically pure	20	O	-	-	+	+	+ O		+	O	+	+	O
				40				+	+	O			O	O	O	O
				60				+	+	-			-	-	-	-
				80												
				100												
				120												
				140												
Ethylene glycol (SpRB)	$HO\text{-}CH_2\text{-}CH_2\text{-}OH$	198	technically pure	20	+	O	-	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	+		+	O	O	O	+
				80					+	+		+	O			O
				100					+	+						
				120						+						
				140												
Ethylene glycol	CH_2OHCH_2OH	198	technically pure	20	+		-	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	O	O	+
				60	+			+	+	+		+	+	+	O	+
				80					+	+			O			O
				100						+						
				120												
				140												
Ethylene oxide	$CH_2\text{-}CH_2$	10	technically pure, moist	20	-	-	-	-	O	+		O	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Ethylenediaminetetra-acetic acid (EDTA)				20				+	+	+		+				
				40												
				60												
				80												
				100												
				120												
				140												
Fatty acids $>C_6$ (SpRB)	R-COOH		technically pure	20	+	+	-	+	+	+		+	+	O	O	-
				40	+	+		+	+	+						
				60	+	+		O	+	+						
				80						+						
				100												
				120												
				140												
Fatty alcohol sulphonates (SpRB)			aqueous	20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	O	O		+	O	+		+	+	+	+	+
				80						+						
				100												
				120												
				140												
Fertilizers			aqueous	20	+	+	O	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+				+			+			+
				100									+			
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Fluorine	F_2		technically pure	20	-	-	-	-	-	-		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Fluorosilicic acid (Q/E)	H_2SiF_6		32%, aqueous	20	+	+	+	+	+	+		+	○	○	○	+
				40	+	+	+	+	+					-	-	○
				60	+	+	+	+	+							-
				80												
				100												
				120												
				140												
Formaldehyde (SpRB)	HCHO		40%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60			+	+	+			+	+	○	○	○
				80												
				100												
				120												
				140												
Formamide	$HCONH_2$	210	technically pure	20	-	-	-	+	+			+	○	+	+	
				40				+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Formic acid (SpRB)	HCOOH		up to 50%, aqueous	20	+	-	○	+	+	+		+	+	-	+	+
				40	+			+	+	+		+	+		+	+
				60	○			+	○	+		○	○		○	+
				80						+			-			○
				100						+						
				120												
				140												
Formic acid (SpRB)	HCOOH	101	technically pure	20	+	-	-	+	+	+		+	+	-	+	+
				40	○			+	○	+		+			○	+
				60	-			+	-	+		+			-	+
				80						+		○				○
				100						+						
				120												
				140												
Formic acid (SpRB)			25%	20	+	+		+	+	+		+				+
				40	+	+		+	+	+		+				+
				60	+	+		+	+	+		+				
				80					+	+						
				100												
				120												
				140												
Freon 113	see trifluoro, trichlorethane	48														
Frigen 12 (D/P)	see Freor 12	-30	technically pure													

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Fruit juices (SpRB)				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+	+	+	+
				100						+		+	+	+		+
				120						+			+			
				140												
Fruit pulp				20	+		+	+	+	+		+		+	+	+
				40				+	+	+						
				60					+	+						
				80												
				100												
				120												
				140												
Fuel oil				20	+		+	O	O	+		-	+	+	+	-
				40	O		+	-	-	+			+	+	O	
				60						+			+	+		
				80						+						
				100						+						
				120												
				140												
Furfuryl alcohol (SpRB)	$C_5H_6O_2$	171	technically pure	20	-	-	-	+	+	+		O	-	-	O	O
				40				+		+						
				60				+	O	O						
				80						-						
				100												
				120												
				140												
Gasoline (SoRB)	C_5H_{12} to $C_{12}H_{26}$	80-130	free of lead and aromatic compounds	20	+	+	-	+	O	+		-	+	+	-	O
				40	+	+		+		+			+	+		-
				60	+	+		O	-	+			+	+		
				80						+						
				100						+						
				120						+						
				140												
Gelatin			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60		+	+	+	+	+						
				80						+						
				100												
				120												
				140												
Glucose	$C_6H_{12}O_6$	Fp*., 148	all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+	+	+	+
				100						+			+			
				120												
				140												
Glycerol	HO-CH_2-CHOH-CH_2OH	290	technically pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		O	+	+	+	+
				60	+	+		+	+	+		O	O	+	+	+
				80		+			+	+			-	O	+	+
				100					+	+					O	+
				120						+						+
				140												O

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Glycocoll (SpRB)	NH_2-CH_2-COOH	Fp.* 233	10%, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			+	O	+	O
				60		+				+						
				80						+						
				100												
				120												
				140												
Glycol	see Ethylene glycol															
Glycolic acid	HO-CH_2-COOH	fp.*, 80	37%, aqueous	20	+	-	+	+	+	+			+	+	+	+
				40			+	+		+						
				60				+		+						
				80						+						
				100						+						
				120												
				140												
Heptane (SpRB)	C_7H_{16}	98	technically pure	20	+	O	-	+	+	+		-	+	+	+	+
				40						+			+	+	+	O
				60				O	O	+			+	+	+	-
				80						+						
				100						+						
				120												
				140												
Hexane (SpRB)	C_6H_{14}	69	technically pure	20	+	O	-	+	+	+		-	+	+	+	+
				40						+			+	+	+	O
				60				O	O	+			+	+	+	-
				80						+						
				100						+						
				120												
				140												
Hydrazine hydrate (SpRB)	H_2N-NH_2 . H_2O	113	aqueous	20	+	-	-	+	+	-		+	O	-	-	+
				40				+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Hydrobromic acid (SpRB)	HBr	124	aqueous, 50%	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		+	+	-	+	+
				60	+	+		+	+	+		O	+		O	+
				80		O				+		-	O		-	O
				100						+			-			-
				120												
				140												
Hydrochloric acid (Q/E, D/P)	HCl		up to 38%	20	+	+	-	+	O	+		+	+	-	O	+
				40	+	+		+		+			+			
				60	+	+				+						
				80						+						
				100						+						
				120												
				140												
Hydrochloric acid (Q/E, D/P)	HCl		5%, aqueous	20	+		+	+	+	+		+	+	O	O	+
				40	+		+	+	+	+		+	+	-	-	O
				60	O			+	+	+		+	+			-
				80					O	+			+			
				100						+						
				120						+						
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Hydrochloric acid (Q/E, D/PI)	HCl		10%, aqueous	20	+	+	+	+	+	+	+	+	○	○	+
				40	+	+	+	+	+	+	+	+	-	-	○
				60	○	+		+	○	+	+	+			-
				80		+			○	+		+			
				100						+					
				120						+					
				140											
Hydrochloric acid (Q/E, D/PI)	HCl		up to 30%, aqueous	20	+	+	○	+	+	+	+	+	-	-	+
				40	+	+	-	+	○	+	+	+			○
				60	○	+		+	○	+	○	○			-
				80		+			-	+					
				100						+					
				120											
				140											
Hydrochloric acid (Q/E, D/PI)	HCl		36%, aqueous	20	+	+	-	+	+	+	○	+	-	-	○
				40	+	+		+	○	+	○	○			-
				60	○	○		+	-	+	-	-			
				80		○				+					
				100						+					
				120											
				140											
Hydrocyanic acid	HCN	26	technically pure	20	+	+	-	+	+	+	+	+	○	○	+
				40	+	+		+	+	+	○	○	-	-	○
				60	○	+		+	+	+					
				80						+					
				100											
				120											
				140											
Hydrofluoric acid	HF			20	+	-	-	+	+	+	-	+	-	-	+
				40	○			+	+	+		+			+
				60	○			○	+	+		○			○
				80						+					
				100						+					
				120											
				140											
Hydrogen	H_2	-253	technically pure	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80		+			-	+	+	+	+	+	+
				100							+	+	+		
				120											
				140											
Hydrogen chloride (Q/E)	HCl	-85	technically pure, gaseous	20	+	+	-	+	+	+	+	+	○	○	○
				40	+	+		+	+	+	+	+	-	-	○
				60	○	+		+	+	+	+	+			-
				80		○				+					
				100											
				120											
				140											
Hydrogen perocide			70%	20	+	+	-	+	+	○	○	+			
				40						○					
				60											
				80											
				100											
				120											
				140											

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Aggressive Medic					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Hydrogen peroxide (SpRB)	H_2O_2		50%, aqueous	20	+	+	-	+	+	O		O	+			
				40												
				60												
				80												
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2		10%, aqueous	20	+	+	-	+	+	O		O	+	O	-	+
				40	+			+	+	O		O	O	-		+
				60	O			+	+	-		-	-			O
				80												-
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2	139	90%, aqueous	20	+		-	+	-	O			O	-	-	O
				40				-								
				60												
				80												
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2	105	30%, aqueous	20	+	+	-	+	+	O		O	+	-	-	+
				40												O
				60												-
				80												
				100												
				120												
				140												
Hydrogen sulphide	H_2S		technically pure	20	+	+	+	+	+	+		+	+	+	O	+
				40	+	+	+	+	+	+		-	+	O	-	O
				60	+	+		O	+	+			O	-		O
				80						+			-			-
				100						+						
				120						+						
				140												
Hydrogen sulphide	H_2S		saturated, aqueous	20	+	+	+	+	+	+		+	+	-	+	+
				40	+	+	+	+	+	+		-	+	-	-	+
				60	O	+		+	+	+			+			O
				80						+			O			-
				100						+						
				120						+						
				140												
Hydroquinone	$C_6H_4(OH)_2$		saturated	20	+	+		+	+			+				
				40	+	+		+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Hydrosulphite	see Sodium dithione															
Hydroxylamine sulfate				20	+			+				+				
				40	+			+								
				60	+			+								
				80												
				100												
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Hydroxylamine sulphate	$(NH_3OH)_2SO_4$		all, aqueous	20	+	+	-	+	+			+	+	+	O	+
				40	+	+		+	+				+	O		+
				60				+	+							
				80												
				100												
				120												
				140												
Iodine-potassium iodide solution (Lugol's solution)				20	+	-	-			+			+			
				40												
				60												
				80												
				100												
				120												
				140												
Iodium	I_2	185	100%	20	-	-	-			+			+			
				40												
				60												
				80												
				100												
				120												
				140												
Iron (III) -chloride			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+			+			
				120												
				140												
Iron (III) -chloride	$FeCl_3$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -nitrate	$Fe(NO_3)_2$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+			+			
				120												
				140												
Iron (III) -chloride	$FeCl_3$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -chloride			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF ISYGEFI		EPDM	FPM	NBR	CR	CSM
Iron (III) -chloridsulfate			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
iron (III) -nitrate			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -nitrate	$Fe(NO_3)_3$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -sulfate	$Fe_2(SO_4)_3$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -sulfate			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -nitrate	FE(NO3)3		saturated	20	+					+		+	+			
				40	+					+		+	+			
				60	+					+		+	+			
				80						+		+	+			
				100						+			+			
				120												
				140												
Iron (II) -sulfate	$FeSO_4$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -sulfate			saturated	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Iron salts			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	○	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100						+			+			
				120						+						
				140												
Isooctane (SpRB)	$(CH_3)_3$-C-CH_2-CH-$(CH_3)_2$	99	technically pure	20	+		-	+	+	+			+	+	+	○
				40						+						
				60				○	○	+						
				80						+						
				100						+						
				120												
				140												
Isophorone (SpRB)	$C_9H_{14}O$		technically pure	20						-						
				40												
				60												
				80												
				100												
				120												
				140												
Isopropyl alcohol (SpRB)	$(CH_3)_2$-CH-OH	82	technically pure	20				+	+	+		+				
				40						+						
				60						+						
				80						○						
				100												
				120												
				140												
Isopropyl ether	$(CH_3)_2$-CH-O-CH-$(CH_3)_2$	68	technically pure	20	-	-	-	○	○	+		○	-	-	-	-
				40						+						
				60				-	-	+						
				80												
				100												
				120												
				140												
Isopropylbenzene				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Jam, Marmalade				20	+	+	+	+	+	+		+	+	+	+	+
				40	○	+	+	+	+	+		+	+	+	+	+
				60	○	+		+	+	+		+	+	+		+
				80					+	+		+	+			
				100					+	+						
				120						+						
				140												
Lactic acid (SpRB)	$CH_3CHOHCOOH$		10%, aqueous	20	+	+	+	+	+	+		○	+	-	-	○
				40	○	+	○	+	+	+		○	○			○
				60	-	+	-	+	+	○		○	○			○
				80		+			+	○		-	○			
				100					+	-						
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF-H		EPDM	FPM	NBR	CR	CSM
Lanolin (SpRBI			technically pure	20	+	o	+	+	+	+			+	+	+	+	o
				40	o		+	+	+	+			+	+	+	o	-
				60			+	+	+	+						-	
				80						+							
				100						+							
				120						+							
				140													
Lead acetate	$PbICH_3COO]_2$		oqueous, saturated	20	+	+	+	+	+	+		+	+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+	+
				80		+				+							
				100						+							
				120													
				140													
Lead salts	$PbCl_2$, $PbINO_3]_2$, $PbSO_4$		saturated	20		+											
				40		+											
				60		+											
				80		+											
				100													
				120													
				140													
Leadcarbonate				20	+	+		+	+	+		+					
				40						+							
				60						+							
				80													
				100													
				120													
				140													
Leadnitrate	$PbINO_3]2$			20		+											
				40		+											
				60		+											
				80		+											
				100													
				120													
				140													
Leadnitrate				20	+					+							
				40	+					+							
				60	+					+							
				80						+							
				100						+							
				120													
				140													
Leadtetrafluoroborate				20						+							
				40						+							
				60						+							
				80						+							
				100						+							
				120													
				140													
Linoleic acid				20						+							
				40						+							
				60						+							
				80						+							
				100						+							
				120													
				140													

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Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Linseed oil (SpRB)			technically pure	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	-	+	+	+			+	+	+	-
				60	○			+	+	+			+	+	-	-
				80					+	+						
				100						+						
				120						+						
				140												
Liqueurs				20	+			+	+	+		+	+	+	+	+
				40	+			+		+						
				60						+						
				80						+						
				100												
				120												
				140												
Liquid fertilizers				20				+	+			+				
				40				+	+			+				
				60				+	+			+				
				80					+							
				100												
				120												
				140												
Lithiumbromide	LiBr			20	+	+		+	+	+		+	+			
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Lithiumsulfate				20	+	+		+	+	+		+	+			
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Lubricating oils				20	+	○	-	+	○	+		-	+	+	+	+
				40	+			+		+			+	+	○	○
				60	+			○		+			+	○	-	-
				80						+			○			
				100						+			-			
				120						+						
				140												
Magnesium salts	$MgCl_2$, $MgCO_3$, $Mg(No3)_2$, $Mg(OH)_2$, $MgSO_4$		all, aqueous, saturated	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			+	+	+	+
				60	○	+	+	+	+	+		+	+	+	+	+
				80		+		+	+	+		+	+			+
				100					+	+						
				120						+						
				140												
Magnesiumhydrogen-carbonate				20	+			+	+			+				
				40	+			+	+			+				
				60	+			+	+			+				
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEFI		EPDM	FPM	NBR	CR	CSM
Maleic acid (SpRB)	$CH\text{-}COOH)_2$	fp. *131	cold saturated, aqueous	20	+	+	+	+	+	+			+	-	-	-
				40	+	+		+	+	+			+			
				60	O			+	+	+			+			
				80						+			-			
				100						+						
				120						+						
				140												
Media water or similar media				20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80		+			+	+						
				100					+	+						
				120						+						
				140						+						
Mercury	Hg	357	pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	+		+	+	+	+	+
				80						+			+			
				100						+						
				120						+						
				140												
Mercury (I) -chloride	$HgCl_2$			20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+						
				100						+						
				120												
				140												
Mercury (II) -cyanide	Hg(CN)2			20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Mercury (II) -cyanide	$Hg(NO_3)_2$			20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+			+			
				100						+						
				120												
				140												
Mercury (II) -sulfate				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+			+			
				100						+						
				120												
				140												
Mercury salts	$HgNO_3$, $Hg\ Cl_2$, $Hg(CN)_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	O	O	O
				40	+	+		+	+	+		+	+	O	O	O
				60	O	+		+	+	+			+	-	-	-
				80						+						
				100						+						
				120						+						
				140												
Methane	see natural gas	-161	technically pure													

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Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Methanol (SpRB)	CH_3OH	65	all	20	+	-	-	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	-		+	+	+	+	+
				80												
				100												
				120												
				140												
Methyl acetate	CH_3COOCH_3	56	technically pure	20	-	-	-	+	+	+			-	-	-	-
				40					+	+						
				60					+	+						
				80												
				100												
				120												
				140												
Methyl amine	CH_3NH_2	-6	32%, aqueous	20	+	-	-	+	+	+			+	-	+	+
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Methyl bromide	CH_3Br	4	technically pure	20	-	-	-	+	-	+			+	-	-	+
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Methyl chloride	CH_3Cl	-24	technically pure	20	-	-	-	+	-	+			-	-	-	-
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Methyl ethyl ketone	$CH_3COC_2H_5$	80	technically pure	20	-	-	-	+	+	-			-	-	-	-
				40				+	+							
				60				-	+							
				80												
				100												
				120												
				140												
Methylene chloride	CH_2Cl_2	40	technically pure	20	-	-	-	+	+	+			+	-	-	-
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Methylisobutylketone	$C_6H_{12}O$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Methylmethacrylate	$C_5H_8O_2$			20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											
Methylphenylketone (Acetophenon)	C_8H_8O			20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											
Milk (SpRB)				20	+		+	+	+	+		+	+	+	+
				40	+		+	+	+	+					
				60	+		+	+	+	+					
				80			+		+	+					
				100					+	+					
				120						+					
				140											
Mineral oils, free of aromatics				20	+		+	-	+	+		+	+	○	○
				40	+				+	+		+	+	-	-
				60	+				○	+		+	+		
				80						+					
				100						+					
				120						+					
				140											
Mineral water				20	+		+	+	+	+	+	+	+	+	+
				40	+		+	+	+	+	+	+	+	+	+
				60	+		+	+	+	+	+	+	+	+	+
				80			+		+	+	+	+	+		+
				100					+	+	+	+			+
				120						+		+			
				140											
Mixed acids - nitric - hydrofluoric - sulphuric	15% HNO_3 15% HF 18% H_2SO_4		3 parts 1 part 2 parts	20	○	○	-	○	-	+		○ +	-	-	○ +
				40						+					
				60						+					
				80											
				100											
				120											
				140											
Mixed acids - sulphuric - nitric - water	H_2SO_4 HNO_3 H_2O		48% 49% 43%	20	+	+	-	-	-	+		-	-	-	-
				40	○										
				60	-										
				80											
				100											
				120											
				140											
Mixed acids - sulphuric - nitric - water	H_2SO_4 HNO_3 H_2O		50% 50% 40%	20	○	○	-	-	-	+		-	-	-	-
				40	-										
				60											
				80											
				100											
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Mixed acids - sulphuric - nitric - water	H_2SO_4 HNO_3 H_2O		10% 87% 43%	20 40 60 80 100 120 140	○	○	-	-	-	○			-	-	-	-
Mixed acids - sulphuric - nitric - water	H_2SO_4 HNO_3 H_2O		50% 33% 17%	20 40 60 80 100 120 140	+ ○	+	-	-	-	+			+	-	-	○
Mixed acids - sulphuric - nitric - water	H_2SO_4 HNO_3 H_2O		10% 20% 70%	20 40 60 80 100 120 140	+ +	+	-	○	-	+ + + +			+ + +	-	○	+ ○
Mixed acids - sulphuric - nitric - water	H_2SO_4 HNO_3 H_2O		50% 31% 19%	20 40 60 80 100 120 140	+		-	-	-	+			+	-	○	○
Mixed acids - sulphuric - phosphoric - phosphoric	H_2SO_4 H_3PO_4 H_2O		30% 60% 10%	20 40 60 80 100 120 140	+ +	+ + +	-	+ ○	+ ○	+ + + +			+ + +	-	○	+ ○
Molasses				20 40 60 80 100 120 140	+ + ○	+ + + +	+ + +	+ + +	+ + +	+ + + +		+ + +	+ + + +	+ + +	+ + ○	+ + +
Molasses wort				20 40 60 80 100 120 140	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +		+ + +	+ + +	+ + +	+ + +	+ + +
Monochloroacetic acid ethyl ester	$ClCH_2COOC_2H_5$	144	technically pure	20 40 60 80 100 120 140	-	-	-	+ + +	+ + +	○ -			○	-	-	-

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Morpholin	C_4H_9NO	129	technically pure	20	-	-	-	+	+	+			+	-	O	O
				40				+	+	+						
				60				+	+	O						
				80												
				100												
				120												
				140												
Mowilith D			usual commercial	20	+	+		+	+	+			+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Naphthalene		218	technically pure	20	-	-	-	+	+	+		-	+	+	-	O
				40						+			+	+		-
				60				O		O			+	+		
				80												
				100												
				120												
				140												
Natriumhydrogensulfite	$NaHSO_3$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+						
				100						+						
				120												
				140												
Natriumsulfate				20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Natriumtetraborate (Borax)				20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+							
				100												
				120												
				140												
Nickel salts	$(CH_3COO)_2Ni$, $NiCl_2$, $Ni(NO_3)_2$, $NiSO_4$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+			+	+	+	+
				80						+			+			
				100						+						
				120						+						
				140												
Nitrating acid	H_2SO_4 HNO_3 H_2O		65% 20% 15%	20						+						
				40												
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Nitric acid (SpRB)	HNO_3			20	+	+	-	+	O	+		+	+			
				40	+	+				+			+			
				60	+	+				+			+			
				80						+						
				100						+						
				120												
				140												
Nitric acid (SpRB)	HNO_3			20	+	+	-	+	O	+		+	+			
				40	+	+		+		+			+			
				60	+	+		+		+						
				80		+				+						
				100						+						
				120												
				140												
Nitric acid up to 55% (SpRB)				20	+	+	-	+	-	+			+			
				40	+	+				+						
				60						+						
				80												
				100												
				120												
				140												
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		6,3%, aqueous													
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		up to 40%, aqueous													
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		65%, aqueous													
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		100%													
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		85%													
Nitric oxide	see Nitrous gases															
Nitrilotriacetic acid	$N(CH_2\text{-}COOH)_3$			20				+	+			+				
				40												
				60												
				80												
				100												
				120												
				140												
Nitrobenzene	$C_6H_5\text{-}NO_2$	209	technically pure	20	-	-	-	+	+	+		-	O	-	-	-
				40				O	+	O						
				60				O		-						
				80												
				100												
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Nitrotoluene (o-, m-, p-)		222-238	technically pure	20	-	-	-	+	+	+		-	O	O	-	-
				40				O	O	+			-	-		
				60						+						
				80						+						
				100						O						
				120												
				140												
Nitrous acid	HNO_2			20	+	+	-	+	-	+		+	+			
				40	+					+						
				60						+						
				80												
				100												
				120												
				140												
Nitrous gases	see Nitric oxide		diluted, moist, anhydrous													
N-Methylpyrrolidon				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
N,N-Dimethylaniline	$C_6H_5NICH_3I_2$		technically pure	20	-	-	-	+	+			+				
				40												
				60												
				80												
				100												
				120												
				140												
n-Pentylacetate				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Oleic acid (SpRB)	$C_{17}H_{33}COOH$		technically pure	20	+	O	-	+	+	+		-	+	O	-	-
				40	+			+	+	+			O	-		
				60	+			O	O	+			-			
				80						+						
				100						+						
				120						+						
				140												
Oleum (SpRB)	$H_2SO_4+SO_3$		10% SO_3	20	-	-	-	-	-	-		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Oleum vapours (SpRB)			traces	20	+	-	-	-	-	-		-	+	-	-	O
				40												
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Olive oil (SpRB)				20	+	-	-	+	+	+		-	+	+	+	+
				40	+			+	+	+			+	+	+	+
				60	+			○	+	+			+	+	+	○
				80					+	+			+			-
				100												
				120												
				140												
Oxalic acid (SpRB)	$(COOH)_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	○	○	○
				40	+	+	+	+	+	+			+	-	-	○
				60	+	+			+	+			○			-
				80		○				+			-			
				100						+						
				120												
				140												
Oxygen	O_2		technically pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+		+	+
				60	+			+	○	+		+	+		+	+
				80						+			+		+	+
				100						○			+			+
				120						○			+			
				140												
Ozone (SpRB)	O_3		up to 2%, in air	20	+	+	-	○	○	○		○	+	-	○	+
				40				-	-							
				60												
				80												
				100												
				120												
				140												
Ozone (SpRB)	O_3		cold saturated, aqueous	20	+	+	-	○	○	○		-	+	-	○	+
				40	+			-	-				○		-	+
				60									-			○
				80												
				100												
				120												
				140												
Palm oil, palm nut oil (SpRB)				20	+	○	+	+	+	+		-	+	+	+	○
				40	-			+	+	+			+	+	○	-
				60				○	○	+			+	○	-	
				80						+						
				100						+						
				120												
				140												
Palmitic acid (SpRB)	$C_{15}H_{31}COOH$	390	technically pure	20	+	-	+	○	○	+		○	+	○	+	○
				40						+			○	-	-	-
				60					-	+			-			
				80						+						
				100						+						
				120						+						
				140												
Paraffin emulsions			usual commercial, aqueous	20	+	+	○	+	+	+		-	+	+	+	+
				40	+	+		+	+	+			+	+	○	-
				60				○	○	+			+	○	-	
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Paraffin oil				20	+		+	+	+	+		-	+	+	+	O
				40	+			+	+	+			+	O	O	-
				60	O			+	O	+			+	O	-	
				80						+			O			
				100						+						
				120						+						
				140												
p-Dibromo benzene	$C_6H_3Br_2$		technically pure	20	-	-	-	O	O	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Perchlorethylene (tetrachlorethylene)	$Cl_2C=CCl_2$	121	technically pure	20	-	-		O	O	+			+	O	-	-
				40						+			+	-		
				60						+			+			
				80						O						
				100						-						
				120												
				140												
Perchlorid acid (SpRB)	$HClO_4$		10%, aqueous	20	+	+	O	+	+	+		O	+	-		+
				40	+	+		+	+	+			+			+
				60	O	+		+	+	+			+			O
				80					+	+			O			-
				100					+							
				120												
				140												
Perchlorid acid (SpRB)			70%, aqueous	20	O	O	-	+	O	+		-	+	-	-	+
				40				O	-	+			+			+
				60				-		+			+			O
				80						+			O			
				100						+						
				120												
				140												
Petroleum			technically pure	20	+	-	-	+	+	+		-	+	+	O	-
				40				+	O	+			+	+	-	
				60				O	O	+			O	+		
				80						+						
				100						+						
				120						+						
				140												
Petroleum ether (SpRB)		40-70	technically pure	20	+	-	-	+	+	+		-	+	+	-	-
				40	+			O	O	+			+	O		
				60	+			O	O	+			O	-		
				80						+						
				100						+						
				120												
				140												
Phenol (SpRB)	C_6H_5-OH	182	up to 10%, aqueous	20	+	+	-	+	+	+			+	-	-	-
				40	O	+		+	+	+			+			
				60				O	+	+		+	+			
				80						+		O	O			
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Phenol (SpRB)			up to 5%	20	+	+	-	+	+	+		+	+	-	-	
				40		+		+	+	+		○	+			
				60				+	+	+			+			
				80						+			○			
				100						○						
				120												
				140												
Phenol (SpRB)	C_6H_5-OH		up to 90%, aqueous	20	○	-	-	+	+	+		-	+	-	-	-
				40				+	+	+			○		○	
				60				○	+	○			-			
				80												
				100												
				120												
				140												
Phenylhydrazine	C_6H_5-NH-NH_2	243	technically pure	20	-	-	-	○	○	○		-	+	-	-	-
				40						-			+			
				60									○			
				80												
				100												
				120												
				140												
Phenylhydrazine hydrochloride	C_6H_5-NH-NH_2.HCl		aqueous	20	○	○	-		+	+			+	○	○	+
				40					○	+			+	-	-	+
				60					○	+		○	○			○
				80									-			-
				100												
				120												
				140												
Phosgene (SpRB)	$COCl_2$	8	liquid, technically pure	20	-	-	-	-	-	-		-	+	○	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Phosgene (SpRB)			gaseous, technically pure	20	+	-	-	○	○	+		+	+	+	+	+
				40	○					+			+	+	○	○
				60	○								○	+	-	
				80												
				100												
				120												
				140												
Phosphate disodique	see d'isodiumphosphate		saturated													
Phosphoric acid	H_3PO_4		up to 30%, aqueous	20	+	+	+	+	+	+		+	+	○	+	+
				40	+	+	+	+	+	+		+	+	○	+	+
				60	○	+	+	○	+	+		○	+	-	+	+
				80		+			+	+			+		○	○
				100						+			+			
				120						+						
				140												
Phosphoric acid			50%, aqueous	20	+	+	+	+	+	+		+	+	○	+	+
				40	+	+	+	+	+	+		○	+	-	+	+
				60	+	+	○	+	+	+			+		○	+
				80		+			+	+			+			+
				100						+			○			○
				120						+						
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEFI)	EPDM	FPM	NBR	CR	CSM
Phosphoric acid			85%, aqueous	20	+	+	+	+	+	+	+	+	-	+	+
				40	+	+	+	+	+	+	O	+		+	O
				60	+	+	O	O	+	+		+		O	-
				80		+			+	+		O			
				100						+					
				120						+					
				140											
Phosphoric acid	H_3PO_4			20	+	+	-	+	+	+	O	+	-	-	-
				40	+	+		+	+	+		O			
				60		+				+		+			
				80						+		O			
				100											
				120											
				140											
Phosphoric acid	H_3PO_4			20	+	+	-	+	+	+		+			
				40	+	+		+	+	+					
				60	+	+			+	+		+			
				80		+			+	+		O			
				100						+					
				120											
				140											
Phosphoric acid tributyl ester	$(H_9C_4O)_3P=O$			20	-	-	-	+	+	-	+	-			
				40											
				60											
				80											
				100											
				120											
				140											
Phosphorous chlorides:				20	-	-	-	+	O	-		+	-	-	+
- Phosphorous trichloride	PCl_3	175	technically pure	40											
- Phosphorous pentachloride	$PCl5$	162		60				O	O						
- Phosphorous oxichloride (SpRB)	$POCl_3$	105		80											
				100											
				120											
				140											
Photographic developer (SpRB)			usual commercial	20	+	+	+	+	+	+	+	+	O	+	+
				40	+	+	+	+	+	+	+	+	O	+	+
				60	O	+	O	O		+					
				80		O									
				100											
				120											
				140											
Photographic emulsions (SpRB)				20	+	+	+	+	+	+	+	+	O	+	+
				40	+	+	+	+	+	+	+	+		+	+
				60		O				+					
				80											
				100											
				120											
				140											
Photographic fixer (SpRB)			usual commercial	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	O			+					
				80											
				100											
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Phthalic acid (SpRB)	$C_6H_5(COOH)_2$	Fp.*, 208	saturated, aqueous	20	+	-	-	+	+	+		+	+	-	+	+
				40	O			+	+	+		O			+	+
				60	-			+	+	+					O	
				80						+						
				100						+						
				120												
				140												
Phthalic acid dioctayl ester	$C_{24}H_{38}O_4$			20	-	-	-	+	+	-		+	-	-		
				40												
				60												
				80												
				100												
				120												
				140												
Picric acid (SpRB)	$C_6H_3N_3O_7$	FP. 122	1%, aqueous	20	+	-	-	+	+	+		+	+	O	O	+
				40						+		+	+	-	-	O
				60						+		+	+			-
				80						+		+	+			
				100						+		+	+			
				120												
				140												
Potash	see potassium carbonate		cold saturated, aqueous													
Potash lye	KOH		50%	20	+	+		+	+	-		+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80												
				100												
				120												
				140												
Potassium (SpRB)	$KMnO_4$		cold saturated, aqueous	20	+	+		+	+	+		+	+	O	O	+
				40	+	+		+	+	+			+	-	-	+
				60	O			O		+			+			+
				80						+			+			
				100						+						
				120												
				140												
Potassium acetate (SpRB)	CH_3COOK		saturated	20	+	+	+	+	+	+		+	-			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+		+				
				100						+						
				120												
				140												
Potassium bichromate (SpRB)	$K_2Cr_2O_7$	107	saturated, aqueous	20	+	+	+	+	+	+		+	+	+	O	+
				40	+	+	+	+	+	+			+	O	-	+
				60	O	+	+	+	+	+			+			+
				80						+						
				100						+						
				120												
				140												
Potassium borate	K_3BO_3		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	+	+	+
				60	O	+	+	+	+	+			+	+	+	+
				80		+										
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF ISYGEFI		EPDM	FPM	NBR	CR	CSM
Potassium bromate	$KBrO_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	O	+	+		+	+	+	+	+
				80		+			+	+			+	+	O	+
				100					+	+				+	O	+
				120						+						
				140												
Potassium bromide	KBr		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+				+			+	O	+	+
				100						+			+	O	O	+
				120						+						
				140												
Potassium carbonate (potash)				20	+	+	+	+	+	O		+				
				40	+	+			+			+				
				60	+	+			+			+				
				80		+										
				100												
				120												
				140												
Potassium chlorate (SpRB)	$KClO_3$		cold saturated, aqueous	20	+	+	+	+	+	O		+	+	+	+	+
				40	+	+	+	+	+			+	+	O	O	+
				60	+	+	+	+	+				+			+
				80		+							+			O
				100									+			
				120												
				140												
Potassium chloride	KCl		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+			+			+
				100					+	+			+			
				120						+						
				140												
Potassium chromate (SpRB)	K_2CrO_4		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+		+	+			+	O	+	+
				60	+	+	+		+	+			+	-	O	O
				80						+						
				100						+						
				120												
				140												
Potassium cyanide	KCN		cold saturated, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			O	+	+	+
				60	+	+	+	+	+	O		+	-	+	O	+
				80		+			+			+		+	-	+
				100												
				120												
				140												
Potassium dichromate	$K_2Cr_2O_7$		saturated	20		+		+	+	+		+	+			
				40		+		+	+	+						
				60		-		+	+	+						
				80		+				+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Potassium fluoride	KF		saturated	20	+	+		+	+	+			+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Potassium Hexacyanoferrate -III	$K_4[Fe(CN)_6]\cdot 3H_2O$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Potassium hydrogen carbonate	$KHCO_3$		saturated	20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+							
				100												
				120												
				140												
Potassium hydrogen sulphate	$KHSO_4$		saturated	20	+	+		+	+			+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80		+			+			+				
				100												
				120												
				140												
Potassium iodide	KJ		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	○	○	+
				60	+	+	+	+	+	+			+	-	-	+
				80		+				+			+			
				100						+						
				120												
				140												
Potassium nitrate	KNO_3		50%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	+	+	+
				60	+	+	+	+	+	+			+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Potassium perchlorate (SpRB)	$KClO_4$		cold saturated, aqueous	20	+	+			+	+		+	+	+	+	+
				40	+	+				+			+	○	○	+
				60	○	+				+			+			+
				80		+				+			+			○
				100												
				120												
				140												
Potassium persulphate (SpRB)	$K_2S_2O_8$		all, aqueous	20	+	+	+	+	+	+		+	+	-	+	+
				40	+	+	+	+	+	+		+	+		+	+
				60	○	+	+	+	+	+			+		+	+
				80						+			+		○	○
				100									+			
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Potassium sulphate	K_2SO_4		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+			+	+	+	+
				80		+				+			+			
				100						+			+			
				120												
				140												
Potassium sulphide	K_2S		saturated	20	+	+		+	+	O		+				
				40	+	+		+	+	O		+				
				60	+	+		+	+	O		+				
				80		+			+			+				
				100												
				120												
				140												
Potassium sulphite	K_2SO_3		saturated	20	+	+		+	+			+				
				40	+	+		+	+							
				60	+	+		+	+							
				80		+										
				100												
				120												
				140												
Potassium-aluminium-sulfate (alum)			50%	20	+	+		+	+	+		+				
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+		+				
				100						+						
				120												
				140												
Pottasium hexacyanoferrate -(III)	$K_3[Fe(CN)_6]$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Pottasium tartrat				20	+			+	+	+		+				
				40	+			+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Pottasiumhydrogensulfite				20	+					+		+				
				40	+					+		+				
				60						+						
				80						+						
				100						+						
				120												
				140												
Pottasiumhypochlorite	KOCl			20	+	O		+	+	O		+	O			
				40												
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Pottasiumperoxodisulfiate	$K_2S_2O_8$		saturated	20	+	+										
				40	+	+										
				60	+	+										
				80		+										
				100												
				120												
				140												
Pottasiumphosphate	KH_2PO_4 und $K_2H\ PO_4$		all, aqueous	20	+	+	O	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	O	O	+
				60	O	+		+	+	+			+	-	-	+
				80		+			+	+			+			+
				100									+			
				120												
				140												
Pottasiumphosphate				20	+				+							
				40	+				+							
				60	+				+							
				80					+							
				100												
				120												
				140												
Propane	C_3H_8	-42	technically pure, liquid	20	+	-	-	+	+	+		-	+	+	-	-
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Propane			technically pure, gaseous	20	+	+	-	+	+	+		-	+	+	+	O
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Propanol, n- and iso- (SpRB)	C_3H_7OH	97 bzw. 82	technically pure	20	+	-	-	+	+	+		+	+	+	+	+
				40	O			+	+	+		+	+	O	+	O
				60	O			+	+	+			+	-	+	O
				80						O						
				100												
				120												
				140												
Propargyl alcohol (SpRB)	$CH\equiv C\text{-}CH_2\text{-}OH$	114	7%, aqueous	20	+	-	-	+	+	+		+	+	+	+	+
				40	+			+	+	O		+	+	+	+	+
				60	+			+	+	O			+	+	O	O
				80												
				100												
				120												
				140												
Propionic acid (SpRB)	CH_3CH_2COOH	141	50%, aqueous	20	+	O	-	+	+	+		+	+	-	O	O
				40	+			+	+	+		+	+		-	-
				60	O			+	+	+			O			
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		FPDM	FPM	NBR	CR	CSM
Propionic acid (SpRBI		141	technically pure	20	+	O	-	+	+	+		+	+	-	-	-
				40	O			O	O	+		O	+			
				60				O	O	+			+			
				80									O			
				100												
				120												
				140												
Propylene glycol (SpRBI	$C_3H_8O_2$	188	technically pure	20	+	-	O	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	O	+	+
				60	+			+	+	+			O	-		+
				80												
				100												
				120												
				140												
Propylene oxide	C_3H_6O	35	technically pure	20	O		-	+	+	+		O	-	-	-	-
				40						O						
				60												
				80												
				100												
				120												
				140												
Pyridine	C_5H_5N	115	technically pure	20	-	-	-	+	O	+		O	-	-	-	-
				40				O	O	-						
				60				O	O							
				80												
				100												
				120												
				140												
Pyrogallol	$C_6H_3(OH)_3$		100%	20						+			+			
				40						+						
				60												
				80												
				100												
				120												
				140												
Ramsit fabric waterproofing agents			usual commercial	20	+			+	+	+		+	+	+	+	+
				40	+					+						
				60	+					+						
				80												
				100												
				120												
				140												
Salicylic acid	$C_6H_4(OH)COOH$		saturated	20	+	+	O	+	+	+		+	+	+	+	+
				40	+			+	+	+		+				
				60				+	+	+		+				
				80						+						
				100												
				120												
				140												
Sea water	see Brine															
Silicic acid	$SiO(OH)_4$			20	+	+	+	+	+			+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80					+							
				100												
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Silicone oil				20	+	+	+	+	+	+		+	+	+	+	+
				40	O	+		+	+	+		+	+	+	+	+
				60	-			+	+	+		+	+	+	O	
				80					+	+						
				100						+						
				120												
				140												
Silver	AgCn		saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+			+	+		+	+			
				60	+	+			+	+		+	+			
				80												
				100												
				120												
				140												
Silver salts	$AgNO_3$, AgCN, AgCl		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+			+	+		+	+			
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	+						
				100						+						
				120												
				140												
Silvercyanide				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+			+	+		+	+			
				60	+	+			+	+		+	+			
				80												
				100												
				120												
				140												
Soap solution (SpRBI			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	O	+			+	+		+	+	+	+	+
				80						+						
				100						+						
				120												
				140												
Soda	see Sodium carbonate															
Sodium acetate	CH_3COONa		all, aqueous	20	+	+	+	+	+	+		+	-	+	+	O
				40	+	+			+	+		+		+	+	
				60	+	+			+	+		+				
				80		+			+	+						
				100					+	O						
				120												
				140												
Sodium aluminium sulfate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Sodium arsenite	$Na_3 AsO_3$		saturated	20	+	+		+	+			+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80		+			+							
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium benzoate	C_6H_5-COONa		cold saturated, aqueous	20	+	+	-	+	+	+		○	+	+	+	+
				40	+	+		+	+	+			+		+	+
				60	○	+		+	+	+			+			○
				80		+				○			○			+
				100						+						
				120												
				140												
Sodium bicarbonate	$NaHCO_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80					+	+		+	+			
				100						+						
				120												
				140												
Sodium bisulphate	$NaHSO_4$		10%, aqueous	20	+	+	+	+	+	+		○	+	○	+	+
				40	+	+	+	+	+	+			+		+	+
				60	○	+	+	+	+	+			+	-	○	
				80						+			+			
				100												
				120												
				140												
Sodium bisulphite	$NaHSO_3$		all, aqueous	20	+	+		+	+	+		+	○	○	+	+
				40	○	+		+	+	+		○	-	-	+	+
				60	-	+		+	+	+		-	-		○	+
				80						+					-	○
				100												
				120												
				140												
Sodium borate	Na_3BO_3		saturated	20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+			
				80		+			+							
				100												
				120												
				140												
Sodium bromate	$NaBrO_3$		all, aqueous	20	+	+		+	+	+		+	+	+	+	+
				40	○	+		○	○	+			+	○	+	+
				60						+			+	-	○	+
				80						+						
				100						+						
				120												
				140												
Sodium bromide	NaBr		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	○	+	+
				60	○	+	+	+	+	+			+		○	○
				80		+			+	+			+			
				100						+						
				120						+						
				140												
Sodium carbonate	see soda		cold saturated, aqueous													
Sodium chlorate (SpRB)	$NaClO_3$		all, aqueous	20	+	+	+	+	+	○		+	+	+	+	+
				40	+	+	+	+	+			+	+	○	+	+
				60	○	+	+	+	+			+	+	-	○	+
				80		+			+			○	+		-	○
				100								-				
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium chlorite (SpRB)	$NaClO_2$		diluted, aqueous	20	O	+		+	+	+		+	+	-	O	+
				40		+		O	O	O		+	+		-	+
				60		+				O		+	+			+
				80		+										
				100												
				120												
				140												
Sodium chromate (SpRB)	Na_2CrO_4		diluted, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+		+	+		+	+	O	+	+
				60	O		+			+		+	+	-	O	O
				80						+						
				100						+						
				120												
				140												
Sodium disulphite	$Na_2S_2O_5$		all, aqueous	20	+	+		+	+	+		+	+	O	+	+
				40	+	+				+		+	+	-	+	+
				60	O	+				+		+	+		+	O
				80						+						
				100						+						
				120												
				140												
Sodium dithionite	see hyposulphite		up to 10%, aqueous													
Sodium fluoride	NaF		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+			+		+	+	+	+	+
				60	+	+	+			+		+	+	O	+	+
Sodium hydroxide (see Caustic soda)				80						+						
				100						+						
				120												
				140												
Sodium hypochlorite (SpRB)	NaOCl		12,5% active chlorine, aqueous	20	+			O	O	O		+	+	-	-	+
				40	+			-	-							
				60	O											
Sodium iodide	NaI		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+			+			+	+	+	+
				60	O	+	+			+			+	O	+	O
				80		+				+						
				100						+						
				120												
				140												
Sodium nitrate	$NaNO_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+		+	+		+	+	+	+	+
				60	O	+			+	+		+	+	+	+	+
				80					+	+						
				100						+						
				120						+						
				140												
Sodium nitrite	$NaNO_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+		+	+			+	O	+	+
				60	+	+	+		+	+			+	-	+	+
				80		+				+						
				100						+						
				120						+						
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Sodium oxalate	$Na_2C_2O_4$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+
				40	+	+				+					
				60	O	+				O					
				80											
				100											
				120											
				140											
Sodium perborate	$NaBO_3\ 4H_2O$		saturated	20	+	+		+	+	+	+	+			
				40	+	+				+					
				60	+	+				+					
				80		+									
				100											
				120											
				140											
Sodium perchlorate	$NaClO_4$		saturated	20	+	+		+	+		+	+			
				40	+	+									
				60	+	+									
				80		+									
				100											
				120											
				140											
Sodium persulphate (SpRB)	$Na_2S_2O_8$		cold saturated, aqueous	20	+			+	+	+	+	+	-	+	+
				40	+			+	+	+	+	+		+	+
				60	O			+	+	+		+		+	+
				80								+		O	O
				100								+			
				120											
				140											
Sodium phosphate	Na_3PO_4		cold saturated, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+			+	+	+	+	+	+	+
				60	O	+			+	+	+	+	+	+	+
				80		+				+	O				
				100						+	-				
				120											
				140											
Sodium silicate	Na_2SiO_3		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+		+	+	+	+	+	+	+	+
				60	O	+			+	+	O	+	+	+	+
				80						+	-				
				100											
				120											
				140											
Sodium Sulfide	Natriumsulfid														
Sodium sulphate	Na_2SO_4, $NaHSO_4$		cold saturated, aqueous	20	+	+	+	+	+	+	O	+	+	+	+
				40	+	+		+	+	+	O	+	+	+	+
				60	O	+		+	+	+	O	+	+	+	+
				80					+	+		+			
				100						+					
				120						+					
				140											
Sodium sulphide	Na_2S		cold saturated, aqueous	20	+	+	+	+	+	O	+	+	+	-	+
				40	+	+	+	+	+	O	+		+		+
				60	O	+	+	+	+	O	+		+		+
				80		+			+						
				100											
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium sulphite	Na_2SO_3		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	O	+	+
				60	O	+		+	+	+		+	+	-	O	+
				80		+			+	+						
				100						+						
				120												
				140												
Sodium thiosulpnate	$Na_2S_2O_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40										O	+	+
				60										-	O	O
				80												
				100												
				120												
				140												
Sodiumchloride	NaCl		each, aqueous	20	+	+	+	+	+	+		+	+			
				40	+	+	+	+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Sodiumcyanide	NaCN			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+							
				100												
				120												
				140												
Sodiumdichromate	Na_2Cs2O_7			20	O	+		+	+			+	+			
				40		+		+				+	+			
				60		+							+			
				80		+										
				100												
				120												
				140												
Sodiumhydrogen-carbonate	$NaHCO_3$			20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+							
				100												
				120												
				140												
Sodiumhydrogensulfate	$NaHSO_4$			20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+						
				100						+						
				120												
				140												
Spindle oil				20	O	O	-	O	+	+		-	+	+	O	-
				40					O	+			O	+	-	O
				60				O	-	+			-	-		-
				80						+						
				100												
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Spinning bath acids containing carbon disulphide (SpRB)			100 mg CS_2/l	20	+			+	+	+			+	-	-	O
				40	+					+						
				60												
				80												
				100												
				120												
				140												
Spinning bath acids containing carbon disulphide (SpRB)			200 mg CS_2/l	20	O			+	+	+		-	+	-	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Spinning bath acids containing carbon disulphide (SpRB)			700 mg CS_2/l	20	-			+	+	+		-	+	-	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Stannous chloride	see Tin II chloride		cold saturated, aqueous													
Stannous chloride - Tin IV chloride	$SnCl_4$		cold saturated, aqueous	20				+	+							
				40				+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Starch solution	$(C_6H_{10}O_5)n$		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+	+
				60	+	+			+	+	+	+	+	+	+	+
				80		+					+					
				100							+					
				120												
				140												
Starch syrup			usual commercial	20	+	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+	+
				60	+	+			+	+	+	+	+	+	+	+
				80		+					+					
				100							+					
				120												
				140												
Stearic acid (SpRB)	$C_{17}H_{35}COOH$	Fp. 69	technically pure	20	+	O	+	+	+	+	+	+	+	+	+	O
				40	+		+			+	+	+	+	+	+	O
				60	+			O	O	+	+	O	O	O	O	-
				80						+						
				100						+						
				120						+						
				140												
Styrol				20	-	-	-			+			+			
				40												
				60												
				80												
				100												
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Succinic acid	$HOOC\text{-}CH_2\text{-}CH_2\text{-}COOH$	Fp.*, 185	aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80									+			
				100												
				120												
				140												
Sugar syrup			usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	O	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80					+	+		+	+			+
				100					+	+						
				120						+						
				140												
Sulfur	S	Fp.*, 119	technically pure	20	O	O	-	+	+	+		+	+	-	+	+
				40	-			+	+	+			+			+
				60				+	+	+			+			+
				80					+	+			+			+
				100						+						
				120						+						
				140												
Sulfur dioxide	SO_2	-10	technically pure, anhydrous	20	+	+	-	+	+	O		+	+	-	-	O
				40	+	+		+	+	O		O	O			-
				60	+	+		+	+	-		-				
				80												
				100												
				120												
				140												
Sulfur dioxide	SO_2		technically pure, moist	20	-	-	-	-	-	-		-	O	-	-	O
				40												
				60												
				80												
				100												
				120												
				140												
Sulfur dioxide	SO_2		all, moist	20	+	+	-	+	+	+		+	+	-	-	O
				40	+	+		+	+	O		O	O			-
				60	O			+	+	-		-				
				80												
				100												
				120												
				140												
Sulfur trioxide	SO_3			20	-	-	-					-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Sulfuric acid saturated by Chlorine	$H_2SO_4+Cl_2$		60%	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sulfuric acid (see note 2.3.1 on jointing)	H_2SO_4	120	up to 40%, aqueous	20	+	+	+	+	+	+		+	+	O		+
				40	+	+	O	+	+	+		+	+	-	O	+
				60	O	+		+	+	+		+	+		+	O
				80		+				+		O	O		O	O
				100						+		-	-		-	-
				120												
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4	140	up to 60%, aqueous	20	+	+	-	+	+	+		+	+	-	-	+
				40	+	+		+	O	+		+	+			O
				60	+	+		+	-	+		O	+			O
				80		+				+		-	O			-
				100						+						
				120						+						
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4	195	up to 80%, aqueous	20	+	+	-	+	+	+		O	+	-	-	+
				40	+	+		+	+	+		O	+			O
				60	+	+		O	O	+		-	O			-
				80		+				+			-			
				100						+						
				120						O						
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4	250	90%, aqueous	20	+	+	-	O	O	+		-	+	-	-	-
				40	+	+				+			+			
				60		+				+						
				80						+						
				100						O						
				120						O						
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4		96%, aqueous	20	+	+	-	-	-	+		-	+	-	-	-
				40	+	+				+			+			
				60	O	+				-						
				80												
				100												
				120												
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4		97%	20	+	+	-	-	-	O		-	+	-	-	-
				40		+										
				60												
				80												
				100												
				120												
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4	340	98%	20	+	+	-	-	-	-		-	O	-	-	-
				40	O	+										
				60		O										
				80												
				100												
				120												
				140												
Sulfurous acid	H_2SO_3		saturated, aqueous	20	+	+	O	+	+	+		+	+	-	-	O
				40	+	+	+	+	+	+		-	+			O
				60	O			+	+	+			O			-
				80						+			-			
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Sulfuryl chloride	SO_2Cl_2	69	technically pure	20	-	-	-	-	-	O		+	-	O	+
				40											
				60											
				80											
				100											
				120											
				140											
Surfactants (SpRB)			up to 5%, aqueous	20	O	-	-	+	+	+	+	+	+	+	+
				40	O				O	O					
				60	O				O	O					
				80						O					
				100											
				120											
				140											
Surfactants (ESC)				20	O	O	O	O	O	O	O	O	O	O	
				40											
				60											
				80											
				100											
				120											
				140											
Tallow (SpRB)			technically pure	20	+	-	-	+	+	+	+	+	+	+	+
				40	+			+	+	+	+	+	+	+	+
				60	+			+	+	+	+	+	+	+	+
				80					+	+					
				100						+					
				120											
				140											
Tannic acid (SpRB)			all, aqueous	20	+	+	+	+	+			+	+	+	+
				40		+	+	+	+						
				60		+		+	+						
				80											
				100											
				120											
				140											
Tanning extracts form plants (SpRB)			usual commercial	20	+	+	+	+	+	+	+	+	+	+	+
				40		+	+								
				60											
				80											
				100											
				120											
				140											
Tartaric acid				20						+					
				40						+					
				60											
				80											
				100											
				120											
				140											
Tartaric acid	HO_2C-CH(OH)-CH(OH)-CO_2H		all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+			+	+	+	+	+	+	+	+
				60	O			+	+	+	+	+	O	+	+
				80						+					
				100						+					
				120						+					
				140						+					

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Tartaric acid up to 10%				20						+					
				40						+					
				60						+					
				80											
				100											
				120											
				140											
Tetrachlorethylene				20	-	-	-	-	-	+	-	+			
				40											
				60											
				80											
				100											
				120											
				140											
Tetrachloroethane	$Cl_2CH\text{-}CHCl_2$	146	technically pure	20	-	-	-	O	O	+	-	O	-	-	-
				40						+					
				60						O					
				80											
				100											
				120											
				140											
Tetrachloroethylene	see Perchloroethylene	121													
Tetraetylene lead (SpRB)	$(C_2H_5)_4Pb$		technically pure	20	+	+	-	+	+	+	O	+	+	O	+
				40						+					
				60						+					
				80						+					
				100						+					
				120						+					
				140											
Tetrahydrofurane	C_4H_8O	66	technically pure	20	-	-	-	O	O	-	O	-	-	-	-
				40											
				60											
				80											
				100											
				120											
				140											
Tetrahydronaphthalene	Teralin	207	technically pure												
Thionyl chloride	$SOCl_2$	79	technically pure	20	-	-	-	-	-	-	O	+	-	-	-
				40											
				60											
				80											
				100											
				120											
				140											
Tin (IV) -chloride				20	+	+				+	+	+			
				40	+	+				+	+	+			
				60	+	+				+	+	+			
				80		+				+		+			
				100						+					
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Tin-(II)-chloride	$SnCl_2$			20				+	+							
				40				+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Toluene	C_6H_5-CH_3	111	technically pure	20	-	-	-	○	○	+		-	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Triacetin (Glycerintriacetat)	$C_9H_{14}O_6$			20	-	-	-	+	+	+		+				
				40						+						
				60												
				80												
				100												
				120												
				140												
Tributylphosphate	$(C_4H_9)_3PO_4$	289	technically pure	20	-	-	-	+	+	+		+	-	-	-	-
				40				+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Trichloroacetic acid	Cl_3C-COOH	196	technically pure	20	○	-	-	+	+	○		○	-	-	-	-
				40				○	+							
				60				-	○							
				80												
				100												
				120												
				140												
Trichloroacetic acid	Cl_3-C-COOH		50%, aqueous	20	+	-	-	+	+	+		○	-	-	-	-
				40	○			+	+	+						
				60				+	○	○						
				80						-						
				100												
				120												
				140												
Trichloroethane	Methylchloroform	74	technically pure													
Trichloroethylene	Cl_2C=CHCl	87	technically pure	20	-	-	-	-	○	+		-	+	-	-	-
				40						+						
				60						+						
				80						○						
				100												
				120												
				140												
Trichloromethane	Chloroform	61														

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Tricresyl phosphate (SpRB)	$H_3C\text{-}C_6H_5\text{-}O)_3PO_4$		technically pure	20	-	-	-	+	+			+	-	O	-	-
				40				+						-		
				60				+	O							
				80												
				100												
				120												
				140												
Triethanolamine (SpRB)	$N(CH_2\text{-}CH_2\text{-}OH)_3$	Fp. *21	technically pure	20	O	-	-	+	+	+		O	-	O	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Triethylamine (SpRB)	$N(CH_2\text{-}CH_3)3$	89	technically pure	20	-	-	-	+	+	O		-	-	-	-	-
				40						-						
				60												
				80												
				100												
				120												
				140												
Trifluoro acetic acid (SpRB)	$F_3C\text{-}COOH$		up to 50%	20	-	-	-	+	+	+		O	-	-	-	-
				40						O						
				60												
				80												
				100												
				120												
				140												
Trioctyl phosphate (SpRB)	$(C_8H_{17})_3PO_4$		technically pure	20	-	-	-	+	+	O		+	-	O	-	-
				40				+	O							
				60												
				80												
				100												
				120												
				140												
Turpentine oil (SpRB)			technically pure	20	+	-	-	O	-	+		-	+	O	-	-
				40	O			O					+			
				60									+			
				80												
				100												
				120												
				140												
Urea (SpRB)	$H_2N\text{-}CO\text{-}NH_2$	Fp.*, 133	up to 30%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+			+	+		+	+	+	+	+
				80		O				+						
				100						O						
				120												
				140												
Urine				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+			+	+		+	+	+	+	+
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Vaseline			technically pure	20	O	O	-	+	O	+		-	+	+	-	-
				40	-					+			+	+		
				60				-	-	+			+	+		
				80						+			+	+		
				100						+			+	+		
				120						+			+			
				140												
Vegetable oils				20	O	-	-	+	+	+		-	+	+	O	O
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Vegetable oils and fats (SpRB)				20	+	O	-	+	+	+		-	+	+	O	O
				40	O			O	+	+			+	+	O	O
				60					O	+			+	+	-	-
				80						+						
				100						+						
				120												
				140												
Vinegar	see wine vinegar															
Vinyl acetate	CH_2=CHOOCCH$_3$	73	technically pure	20	-	-	-	+	+	+		+	-	-	-	-
				40				+		-						
				60					O							
				80												
				100												
				120												
				140												
Viryl chloride	CH_2=CHCl	-14	technically pure	20	-	-	-	-	-	+		-	+	-	-	
				40						+						
				60												
				80												
				100												
				120												
				140												
Viscose spinning solution				20	+	-	-	+	+	+			+	-	O	+
				40	+			+	+	+		+	+		O	+
				60	+			+	+	+		+	+		-	+
				80												
				100												
				120												
				140												
Waste gases containing - Alkaline				20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	O		+	+	+	+	+
				60	+	+		+	+	-		+	+	+	+	O
				80		+			+			+	O			-
				100									-			
				120												
				140												
Waste gases containing - Carbon oxides			all	20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100						+			+			
				120						+						
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Waste gases containing - Hydrochloric acid			all	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	O	+		+	+		+	+
				80		+				+		O	+			+
				100						+			+			
				120						+						
				140												
Waste gases containing - Hydrogen fluoride (SpRB)			traces	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	+	+		O	+	-	O	+
				80		+				+		+	+	O	+	
				100						+				+		
				120												
				140												
Waste gases containing - Nitrous gases			traces	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	O	+		+	+		O	+
				80		+				+		O	+			O
				100						+			O			
				120												
				140												
Waste gases containing - Sulphur dioxide			traces	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	+	+		+	+		+	+
				80		+			+	+		+	+			+
				100						+			+			
				120												
				140												
Waste gases containing - Sulphur trioxide (SpRB)			traces	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	O	+		+	+		+	+
				80		+				+		O	+			
				100						+						
				120												
				140												
Waste gases containing - Sulphuric acid			all	20	+	+		+	+	+		+	+	O	+	+
				40	+	+		+	+	+		+	+	-	+	+
				60	+	+		+	O	+		O	+		+	+
				80		+				+			+			+
				100						+						
				120												
				140												
Water - distilled - deionised	H_2O	100		20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		-	+	+	+	+
				80		+			+	+		-	+	+		+
				100					+	+			+	+		
				120						+			+			
				140												
Water, condensed				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		O	+	+	+	+
				80		+				+			+	O		+
				100						+						
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Water, drinking, chlorinated				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		O	+	+	+	+
				60	+	+	+	+	+	+			+	+	+	+
				80					+	+			+	O		+
				100					+	+			+				
				120						+							
				140													
Water, waste water without organic solvent and surfactants				20	+	+	+	+	+	+			+	+	+	+	
				40	+	+	+	+	+	+		+	+	+	+	+	
				60		+	+	+	+	+		O	+	+	+	+	
				80		+			+	+			+	+		+	
				100						+				O			
				120						+							
				140													
Wax alcohol (SpRB)	$C_{31}H_{63}OH$		technically pure	20	+	O	-	O	O	+		+	+	+	+	-	
				40	+			-	-	+		+	+	+	+		
				60	+					+		+	+	+	+		
				80													
				100													
				120													
				140													
Wine vinegar (SpRB)			usual commercial	20	+	o	O	+	+	+		+	O	-	O	+	
				40	+			+	+	+			-		-	O	
				60	+			+	+	+						-	
				80					+	+							
				100						+							
				120													
				140													
Wines, red and white			usual commercial	20	+	O	+	+	+	+		+	+	+	+	+	
				40			+	+	+	+							
				60				+	+	+							
				80						+							
				100						+							
				120													
				140													
Xylene	$C_6H_4(CH_3)_2$	138? 144	technically pure	20	-	-	-	-	-	+		-	+	-	-	-	
				40						+			-				
				60						O							
				80						-							
				100													
				120													
				140													
yeasts			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+	
				40	+	+			+	+		+	+	+	+	+	
				60		+			+	+							
				80		+				+							
				100													
				120													
				140													
Zinc salts	$ZnCl_2$, $ZnCO_3$, $Zn(NO_3)_2$, $ZnSO_4$		all, aqueous	20	+	+	+	+	+	+			+	+	+	+	
				40	+	+	+	+	+	+		+	+	O	+	+	
				60	O	+		+	+	+		+	+	-	+	+	
				80						+							
				100						+							
				120						+							
				140													

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Zinccarbonate				20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+						
				120												
				140												
Zincchloride			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincnitrate	$ZnINO_3I_2$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincoxide			Suspension	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Zincphosphate			saturated	20	+	+	O	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincstearate			Suspension	20	-	-	-	+	+	+		+	O			
				40				+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Zincsulfate	$ZnSO_4$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+						
				120												
				140												
1-Chloropentan	$C_5H_{11}Cl$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												

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CHEMICAL RESISTANCE OF PLASTICS AND ELASTOMERS

Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
1,1,2-Trifluoro, 1,2,2-Trichloroethane (Freon 113) (SpRB)	$FCl_2C\text{-}CClF_2$	47	technically pure	20	+		-			+		+	+	+	+
				40	+										
				60											
				80											
				100											
				120											
				140											

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CHAPTER 10
SLIPLINING SEWERS

The sliplining of sewers with PE pipe is a fine way to rehabilitate old sewers. By inserting PE pipe in old sewers you can create a new, smooth, watertight interior surface that is far less prone to problems. Standard procedure is to have a continuous length of watertight lining extend from one manhole to the next.

Polyethylene material used to manufacture pipe and fittings for sliplining is either a high-density polyethylene or a minimum polyethylene. These materials must meet or exceed the minimum requirements for cell class 334433 or cell class 234333, respectively, in accordance with ASTM D 3350. Check all ASTM standards prior to making an installation.

There are several considerations that must be reviewed prior to the sliplining procedure. You will need to establish the minimum anticipated clearance that will exist between the lining material and the existing sewer pipe. Flow capacity is another factor to establish. Will there be external loads on the pipe? What will the earth load be? Is hydrostatic pressure expected? Internal pressure and construction loads are additional considerations. How will structural support of the pipe be creating with grouting?

When large sewers are to be lined, they can be examined with video cameras. When you can't gather visual data, it is generally acceptable to plan on a lining diameter that is approximately 10 percent smaller than the diameter of the existing sewer pipe. A difference of five percent is sometimes acceptable when the sewer pipe has a minimum diameter of 24 inches. A liner may float if its diameter is too small. This is a especially true when a force main is lined.

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Solid wall PE made in standard outside diameters and to standard dimension ratios (SDR). ASTM has a standard series of rations from which SDRs are developed. The formula for finding a SDR is fairly simple. You divide the specified outside diameter by the specified minimum wall thickness for pipe of solid wall construction. Evaluation of the SDR will show that the lower the SDR, the stiffer the pipe wall. When working with force mains, the SDR must be based on pressure requirements for the system.

When profile wall pipe is to be used, it's important to remember that it is based on standard inside diameters and ring stiffness constants (RSC). This, of course, is in accordance with ASTM requirements. Profile wall pipe can have reinforced walls to strengthen the pipe against diametrical deformation. To obtain a RSC value, you divide the parallel plate load in pounds per foot of pipe length by the deflection. Standard inside diameters for this type of pipe range from 18 to 120 inches.

Sufficient flow capacity for the anticipated hydraulics of a rehabilitated sewer system can be ensured by choosing the proper inside diameter for the pipe liner. Wall stiffness of a liner pipe must be adequate to withstand external pressure from such things as ground water.

PREPARATION

In preparation of lining a sewer there are steps to be taken on the job site. As you might imagine, the existing sewer pipe has to be cleaned. When feasible, a video inspection should be made of the interior of the sewer. In many cases the flow of sewage must be diverted. This can be done by plugging an upstream manhole and pumping sewage to a manhole that is downstream of the work area. A pipe liner that is joined with gaskets can be installed in a flow stream. The decision to divert sewage flow is one that has to be made on a case-by-case basis. Jobs that require more than one day to complete must be equipped to make a temporary tie-in during the time that work is stopped.

BLOCKAGES

All blockages must be removed. Any obstruction is a risk and must be removed. Depending upon the circumstances, excavation may be required to remove blockages. Care should be taken when making decisions on excavation plans. For example, plan an excavation that will minimize traffic congestion. It's not uncommon for sliplining to be inserted in two directions from a single excavation site. This can greatly reduce the disturbance of traffic and other forms of complications related to excavations.

When digging a pit to work in, the excavation should be sloped at a 2.5 to 1 slope. All safety procedures should be followed to prevent personal injury. If the

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liner pipe will be of a gasket type, the excavation will need to be long enough to allow the length of pipe to be worked with to be inserted in the sewer. In addition, the pit must be long enough to allow workers to join and insert the liner. When fused pipe is used, the length of the excavation should be at least 12 times the diameter of the liner pipe, plus the sloping ends of the work pit.

How wide should a work pit be? At a minimum, it should be as wide as the diameter of the existing sewer, plus 12 inches. Sewers with diameters of between 18 to 48 inches call for a work pit that is as wide as the pipe diameter, plus 18 inches. A sewer with a diameter of 48 inches, or more, will require a width of the outside diameter, plus 24 inches. All bracing and sheeting must be established as required by local conditions and pertinent regulations.

INSTALLATION

Before installation, the top of the existing sewer has to be exposed. It should be exposed to the spring line and the crown of the pipe must be removed for the full length of the work pit. Be careful when removing the top of the existing sewer. Try not to disturb the bottom of the sewer. If the bottom surface of the existing sewer can be maintained it will serve as a solid support for the liner.

In most cases, fused-joint liners are joined outside of the existing sewer. Thermal-butt-fusion or the thermal extrusion welding method is used to join the liner. If SDR solid wall PE pipe is being used as a liner, it may be joined with the use of a stainless steel full encirclement clamp and the proper gasket material. This method is used when the work pit is not at a manhole. Sections of PE pipe with gasket joints can be assembled in the work pit with flow passing through the previously inserted sections.

A power winch and steel cable that is connected to the end of the liner by use of a pulling head is used to insert fused or welded liners. The length of the liner pipe is determined by the capacity of the winch drum and how much power the winch has. There is some risk that the liner pipe will be damaged during insertion. Take this into consideration and make all reasonable efforts to assure a smooth insertion. Once the winch is turned on and the slipliner is being inserted, the process should not be stopped until the liner is in place. Sometimes a pushing-and-pulling process is used to insert a liner. The choice is largely that of the contractor.

There will be a period of relaxation and thermal equilibrium before the liner is ready to be grouted. Check manufacturer recommendations on how long you should wait before sealing the annular space between the liner and the existing sewer.

When lining a sewer with gasket-joined pipe, the pipe is lowered into the work pit one piece at a time. The pipe sections are joined in the pit and then inserted into the sewer. Don't allow the liner to float within the existing sewer. Equal force should be used as the insertion is made.

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GROUTING

Grouting is used to stabilize and support some liner installations. The liner must be protected during grouting. There are two options. Enter the grouting material at a very low pressure, or fill the liner with water to pressurize it during the grouting procedure. The liner manufacturer can provide complete specifications on how much grouting pressure the lining material can be subjected to.

In addition to grouting between the liner and the sewer, you will also have to seal the annular space between the liner and where it enters and exists a manhole. A rule of thumb is to install a sealant for a distance equal to 1½ times the pipe diameter of the liner. Wait until relaxation and thermal equilibrium has settled in. Normally, this will not take more than 24 hours, but check manufacturers' recommendations to confirm a satisfactory waiting period.

If a foam sealant is used to seal the manhole locations, the foam should not protrude into the manhole. It should be finished off flush and covered with a quick-setting, non-shrinking cement.

CONNECTIONS

Connections to the new liner will be needed once the liner installation is complete. This requires a portion of the old sewer be removed at the service connections. Once the liner is exposed, connection can be made. The connection to the liner is made with a heat-fusion saddle or a strap-on saddle. If a strap-on saddle is used, it must be held in place with stainless steel clamps. A neoprene gasket is inserted between the liner and the strap-on saddle. Connections made to the saddle fittings are made with boots, full-encirclement clamps, or some other approved method.

The next step is sealing the open space between the old sewer and the grout or liner. This requirement prevents invasion of ground water, backfill material, and other debris. Once this is done, you are ready to backfill the work area.

BACKFILLING

Before backfilling, all exposed PE pipe and components must be protected. This is done by encasing them with a cement-stabilized sand or some other suitable high-density material. All soil and debris should be removed from the area to be encased. Once the encasement material is in place and approved, the backfilling process may begin. All laterals must be supported prior to being backfilled. Normal backfilling procedures are then used to repair the work area.

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SLIPLINING SEWERS

COST EFFECTIVENESS

Sliplining is a cost-effective means of refurbishing old sewers. The process is much less costly than full sewer replacement. In addition to the financial savings, the sliplining process is far less intrusive on local traffic and other activities than a full replacement would be. PE pipe is a very versatile material that can be used for numerous cost-saving applications.

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CHAPTER 11
TESTING

The inspection and testing of a new installation is essential to a safe installation. Suitable testing is required by various codes. Even if official testing and inspection is not required, common sense would call for careful testing and inspection. Testing methods differ between pressurized pipe and nonpressurized pipe.

Air pressure is often used on nonpressurised installations during testing. But, air and gasses should never be used when testing pressurized systems. There is far too much risk of property and personal damage when a pressurized system is tested with air. Potable water is the preferred medium for testing pressurized systems.

Test methods can also vary between underground installations and aboveground installations. Additionally, some leakage is sometimes allowed for certain types of underground pipelines. Leakage is not allowed in aboveground installations. Another consideration is the type of pipe and joints being tested. For example, systems constructed with solvent-welded joints require plenty of curing time before being tested. Piping installed with mechanical connectors can be tested right away.

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When testing a plastic piping system, the test section should be restrained from sudden uncontrolled movement in the event of rupture. If expansion joints are in the system, they should be temporarily restrained, isolated, or removed during the pressure test. When testing a piping system, the test may be conducted on the entire system, or in sections. The test section size is determined y test equipment capability. If the pressurizing equipment is too small, it may not be possible to complete the test within allowable testing time limits. If so, higher capacity test equipment, or a smaller test section may be necessary.

A key point in determining the length of the test section is that the longer the section, the harder it may be to find a leak. If possible, test medium and test section temperatures should be less than 100°F. At temperatures above 100°F, reduced test pressure is required. Before applying test pressure, allow the required time for the test medium and the test section to temperature equalize. If in doubt about the testing procedures for a particular application, contact the pipe manufacturer for technical assistance. Pressure testing procedures may or may not be applicable depending upon piping products and/or piping applications.

Valves or other devices may limit the test pressure. Such components may not be able to withstand the required test pressure, and should be either removed from, or isolated from the section being tested to avoid possible damage to these components. For continuous pressure systems where test pressure limiting components or devices have been isolated, or removed, or are not present in the test section, the maximum allowable test pressure is 1½ times the system design pressure at the lowest elevation in the section under test. If the test pressure limiting device or component cannot be removed or isolated, then the limiting section or system test pressure is the maximum allowable test pressure of that device or component. For non-pressure, low pressure, or gravity flow systems, consult the piping manufacturer for the maximum allowable test pressure.

The time of a pressure test is often dictated by the applicable code. If there is no code requirement, a good rule of thumb is to conduct a four-hour test. Pressure testing time should not exceed eight hours. If the pressure test is not completed due to leakage, equipment failure, etc., the test section should be depressurized and allowed to "relax" for at least eight hours before bringing the test section up to test pressure again.

Test equipment and the pipeline should be examined before pressure is applied to ensure that connections are tight, necessary restraints are in place and secure, and components that should be isolated or disconnected are in fact, isolated or disconnected. All low pressure filling lines and other items not subject to the test pressure should be disconnected or isolated.

The two types of pressure testing are hydrostatic and pneumatic. Hydrostatic pressure testing with clean water is the preferred method. The test section should be completely filled with the test medium, taking care to bleed off any trapped air. Venting at high points may be required to purge air pockets while the test section is filling.

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Pneumatic testing of the plastic piping system may be conducted with compressed air or any pressurized gas. However, pneumatic pressure testing my present severe hazards to personnel in the vicinity of lines being tested. Extra personnel protection precautions should be observed when a gas under pressure is used as the test medium. Pneumatic testing should not be used unless the Owner and responsible Project Engineer specify pneumatic testing or approve its use as an alternative to hydrostatic testing.

The testing medium should be non-flammable and non-toxic. Leaks may be detected using mild soap solutions or other not-deleterious leak detecting fluids applied to the joint. Bubbles indicate leakage. After leak testing, all soap solutions or leak-detecting fluids should be rinsed of the system with clean water.

After pressure testing, cleaning the piping sysem is often required. If cleaning is required, sedimentation dpepostis can often be flushed from the system using high-pressure water. Water-jet cleaning uses high-pressure water from a nozzle that is pulled through the pipe system with a cable. Pigs may also be used to clean pressure piping systems. Pigging involves forcing a plastic plug (soft pig) through the pipeline. The pig is forced down the pipeline by hydrostatic or pneumatic pressure that is applied behind the pig. When using pigs to clean a pipeline, a pig launcher and a pig catcher is required. A pig launcher is a wye or a removable spool. In the wye, the pig is fitted into the branch, then the branch behind the pig is pressurized to move the pig into the pipeline and downstream. In the removable pipe spool, the pig is loaded into the spool, the spool is installed into the pipeline, and then the pig is forced downstream. A pig may discharge from the pipeline with considerable velocity and force. The pig catcher is a basket or other device at the end of the line designed to receive the pig when is discharges from the pipeline. The pig catcher provides a means of safe pig discharge from the pipeline. Soft pigs must be used with plastic pipe. Brush type pigs may severely damage a plastic pipe and must not be used.

LOW-PRESSURE TEST

A low-pressure test is normally conducted prior to a high-pressure test. The low-pressure test is done prior to the piping being covered or concealed. Generally, the test pressure should never exceed 50 pounds per square inch (PSI). Initial testing should be done to detect any leaks that will be evident at low pressure. The duration of an initial test varies and should always be maintained long enough to allow the detection of any leaks.

A standard pressure gauge can be used to monitor any pressure drops. However, it can take hours of observation to see if the pressure gauge indicates any leaks. In the meantime, a visual inspection of all joints can be helpful in locating leaks. It's rare for pipe to leak along its length, but this can happen. For example, PVC pipe that was dropped on a hard surface can crack and leak when tested. PE pipe that has been punctured can also leak along a section of pipe.

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When conducting a test, maintain the test conditions long enough to find all leaks. Any leaks missed on an initial test can be much more costly to repair when an installation is complete and concealed. It is wise to wait at least 24 hours before testing pipelines that include solvent-welded joints. In some cases with larger pipe and fittings, the drying time will be longer. This is especially true in cold weather. Waiting up to 48 hours to conduct a test may be wise when working with large pipe in cold temperatures.

HIGH-PRESSURE TEST

A high-pressure test is needed before a piping system is put into service. It is often recommended that a high-pressure test be maintained for at least 12 hours. Pipe rupture is a risk during high-pressure testing. Therefore, nonessential personnel should vacate the test area during testing.

Water hammer can be a problem when performing a hydrostatic, high-pressure test. If water is introduced into a piping system too quickly a water hammer can result. This can damage the piping and should be avoided. Water hammer can be avoided by introducing water into a system at lower velocities.

UNDERGROUND PIPING

Underground piping must be secured prior to testing. This is done with bracing and partial backfilling. If proper precautions are not taken in advance, the testing procedure could cause pipe movement and potential damage. Thrust blocks at fittings should be in place prior to testing.

Air will need to be purged from a pipeline that is being tested with water. Provisions for air relief must be installed on the pipeline prior to testing. Ends of the pipe must be capped to prevent leakage during testing. Bracing may be needed to keep the test caps in place when they are under pressure. For example, the thrust at the end of a 100-foot run of 2-inch pipe is 455 pounds. The thrust on a 100-foot length of 8-inch pipe is 5,930 pounds.

Nonpressurized, underground piping is often tested by filling vertical risers with water. A ten-foot head of water over a pipeline can be all that is needed. If the pipeline will have manholes or cleanouts at grade level, the risers are already in place. It's common for several risers to be installed along a pipeline. This is a simple way of testing, but fluctuations in air temperature can cause the static head of water in the risers to move. Don't let this movement fool you when looking for leaks.

It can take a lot of water to fill a pipeline. This generally is not a problem, but there are times when water must be hauled to a site and pumped or poured into a pipeline for testing. Reaching 160 psi in a 2-inch pipe that is 100 feet long will take 20 gallons of water. The same conditions with an 8-inch pipe would require

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259 gallons of water. When the water is released it must have a place to go. Keep this in mind when you are planning your test procedures. The test pressure should never be more than 1.5 times the designed maximum operating pressure of the pipe, fittings, valves, or other elements included in the test. Usually, a test pressure that is 50 psi over the designed maximum operating pressure will be sufficient. The best advice on test pressure is to consult code requirements and manufacturers' recommendations.

TEST CAPS

The removal of test caps can be dangerous. Over the years I've seen several workers come close to serious accidents when removing test gear. Create a safety procedure for removing test equipment and enforce the safety rules. Inspectors will sometimes require test equipment to be removed in their presence so that they can see firsthand that a full test has been applied. There are many tricks of the trade that have been used from time to time to fool inspectors. Seasoned inspectors know most of the tricks and may require proof of testing. Removing an inflatable test ball or a cap can result in a lot of pressure at the point of removal. Make sure that no one is in front of that force.

ABOVE GROUND TESTS

Above ground tests are very similar to those used with underground systems. However, while limited leakage may be allowed in some situations with an underground system, no leakage is allowed in an above ground system. Before conducting any tests, you should consult the designer of the system to be tested. If there are no engineered specifications for testing, contact the manufacturers of materials installed in the piping system to obtain ideal test pressure.

Don't cut corners when testing and inspecting a system. Any time saved in rushing a test will likely be lost in making additional tests and repairs later. In addition to potential financial losses, the risk of personal injury is always a serious consideration. Play by the rules and make your tests and inspections effective.

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Source: PLASTIC PIPING HANDBOOK

CHAPTER 12
PROTECTING PUBLIC SAFETY THROUGH EXCAVATION DAMAGE PREVENTION

Source: National Transportation Safety Board
Safety Study NTSB/SS-97/01, Washington, D.C.

INTRODUCTION

Pipeline accidents result in fewer fatalities annually than accidents in the other modes of transportation; however, a single pipeline accident has the potential to cause a catastrophic disaster that can injure hundreds of persons, affect thousands more, and cost millions of dollars in terms of property damage, loss of work opportunity, community disruption, ecological damage, and insurance liability. In March 1994, a pipeline accident in Edison, New Jersey, injured 112 persons, destroyed eight buildings, and resulted in the evacuation of 1,500 apartment residents [1]. Accident damage exceeded $25 million. The National Transportation Safety Board's investigation determined that the probable cause.of the accident was excavation damage to the exterior of a 36-inch gas pipe. Less than 3 months later, a gas explosion in Allentown, Pennsylvania, resulted in 1 fatality, 66 injuries, and more than $5 million in property damage [2]. The Safety Board concluded that the accident was caused by a service line that had been exposed during excavation and had subsequently separated at a compression coupling.

A propane gas explosion on November 21, 1996, in the Rio Piedras shopping district of San Juan, Puerto Rico, resulted in 33 fatalities and 69 injuries. This accident, one of the deadliest in pipeline history, made 1996 a record year for pipeline fatalities. The San Juan accident accounted for more fatalities than occurred the entire previous year, and it vividly illustrates the tragic potential of a single excavation damaged pipe.

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The Safety Board determined that the probable cause of the propane gas.explosion, fueled by an excavation-caused gas leak in the basement of the Humberto Vidal, Inc., office building, was the failure of San Juan Gas Company, Inc., to oversee its employees' actions to ensure timely identification and correction of unsafe conditions and strict adherence to operating practices; and to provide adequate training to employees [3].

Also contributing to the explosion was the failure of the Research and Special Programs Administration/Office of Pipeline Safety to effectively oversee the pipeline safety program in Puerto Rico; the failure of the Puerto Rico Public Service Commission to require San Juan Gas Company, Inc., to correct identified safety deficiencies; and the failure of Enron Corporation to adequately oversee the operation of San Juan Gas Company, Inc. Contributing to the loss of life was the failure of San Juan Gas Company, Inc., to adequately inform citizens and businesses of the dangers of propane gas and the safety steps to take when a gas leak is suspected or detected.

In 1994, a tragic pipeline accident occurred in Caracas, Venezuela. A 22-ton trenching device, working on a road construction project, struck a 10-inch gas transmission line. An occupied bus and cars stopped by the road construction were engulfed in flames. Fifty-one persons were killed and 34 injured. The next year, in April 1995, construction work on a subway system in Taegu, Korea, ruptured a gas line, killing 103 persons. These accidents occurred in systems that do not operate under U.S. regulations, but they illustrate the catastrophic consequences that can result from excavation damage to underground facilities [4].

Excavation and construction activities are the largest single cause of accidents to pipelines. Data maintained by the U.S. Department of Transportation (DOT), Research and Special Programs Administration (RSPA), Office of Pipeline Safety (OPS), indicate that damage from outside force is the leading cause of leaks and ruptures to pipeline systems, accounting for more than 40 percent of the reported failures [5]. According to the data, two-thirds of these failures are the result of third-party damage; that is, damage caused by someone other than the pipeline operator. Reports from the 20 th World Gas Congress confirm that excavator damage is also the leading cause of pipeline accidents in other countries [6].

According to the Network Reliability Steering Committee (NRSC), an industry group appointed by the Federal Communications Commission, excavation damage is also the single largest cause of interruptions to fiber cable service. Network reliability data, compiled since 1993 by NRSC, show that more than half of all facility outages are the result of excavation damage (53 percent), and in more than half of those cases (51 percent), the excavator failed to notify the facility owner or provided inadequate notification [7]. The Safety Board's review of NRSC first quarter data for 1997 indicates that this relationship has not changed. In addition to being expensive and inconvenient, disruption of the telecommunications network can have significant safety implications, such as impact on traffic control systems, health services, and emergency response activities. The Federal Aviation Administration's (FAA) study of cable cuts in 1993 documented 1,444 equipment outages or communications service disruptions result-

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ing from 590 cable cuts nationwide over a 2-year period. The majority of cable cuts were relatedto construction and excavation activities [8]. For 1995, the FAA's National Maintenance Control Center documented cable cuts that affected 32 air traffic control facilities, including five en route control centers. Cable cuts for the first 8 months of 1997 affected air traffic control operations for a total of 158 hours [9].

The Safety Board has long been concerned about the number of excavation-caused pipeline accidents. Because of several excavation-caused pipeline accidents that occurred between 1968 and 1972, the Safety Board sponsored a symposium on pipeline damage prevention [10]. Many of the proposals developed at that April 1972 symposium led to a Safety Board special study on damage prevention and recommendations that resulted in many of the concepts and systems that have now been implemented to minimize excavation-caused damage to pipelines; for example, the local utility location and coordinating councils (ULCCs) established by the American Public Works Association (APWA) [11]. Since that symposium, the Safety Board has continued to support the initiatives of the APWA, the States, and the national organizations to reduce excavation damage to pipelines. The Safety Board has been an advocate of strong damage prevention programs through its recommendation process and through testimony before Congress and State legislatures, and before groups and trade associations interested in pipeline safety, such as the Interstate Natural Gas Association of America (INGAA), the American Public Gas Association (APGA), the Association of Oil Pipe Lines (AOPL), the American. Gas Association (AGA), and the American Petroleum Institute (API).

The combined efforts of industry, the States, the Safety Board, and other Federal agencies led to a decrease in the number of accidents during the 1980s. Nevertheless, excavation-caused damage remains the largest single cause of pipeline accidents. The Board is currently investigating three other accidents that involved excavation: Gramercy, Louisiana; Tiger Pass, Louisiana; and Indianapolis, Indiana [12].

In response to six serious pipeline accidents during 1993 and 1994 that were caused by excavation damage and to foster improvements in State excavation damage prevention programs, the Safety Board and RSPA jointly sponsored a workshop in September 1994 [13, 14]. This workshop brought together about 400 representatives from pipeline operators, excavators, trade associations, and local, State, and Federal government agencies to identify and recommend ways to improve prevention programs.

On May 20, 1997, the Safety Board updated its "Most Wanted" list of safety improvements to include excavation damage prevention [15]. The Board's recommendations on this issue address requirements for excavation damage prevention programs; comprehensive education and training for operators of buried facilities and the public; and effective government monitoring and enforcement.

This safety study, "Protecting Public Safety Through Excavation Damage Prevention," was initiated to analyze the findings of the 1994 workshop, to discuss industry and government actions undertaken since the workshop, and to formalize

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recommendations aimed at further advancing improvements in excavation damage prevention programs. Chapter 2 of the study provides some background information on the subsurface infrastructure and an overview of pertinent regulatory and legislative initiatives. Chapter 3 discusses the various components of a damage prevention program, Chapter 4 discusses the accuracy of information regarding buried facilities, Chapter 5 addresses system performance measures, and the last sections contain the Safety Board's conclusions and recommendations.

OVERVIEW OF SUBSURFACE INFRASTRUCTURE AND REGULATORY AND LEGISLATIVE INITIATIVES

Subsurface Infrastructure

The term "underground facilities" generally refers to the buried pipelines and cables that transport petroleum, natural gas, electricity, communications, cable television, steam, water, and sewer. These subsurface networks are constructed of cast iron, steel, fiberglass, copper wire, concrete, clay, plastic, or optical fiber depending on the age of the system and its product content. In addition to being categorized by product type and structural components, underground networks are further grouped according to function (gathering, transmission, distribution, service lines); owner (public utility or private industry);.or jurisdiction (municipalities, State, and Federal agencies). The U.S. underground infrastructure comprises about 20 million miles (32.2 million kilometers) of pipe, cable, and wire [16].

Pipeline regulation and oversight by DOT distinguishes between the transport of carbon dioxide, hazardous liquids, and gas. Hazardous liquid lines carry petroleum, petroleum products, or anhydrous ammonia. Their functions include gathering lines that transport petroleum from a field production facility to the primary pumping stations. Trunk lines differentiate a line-haul function for the transport of crude oil to refineries and product from the refineries. Gas lines are categorized as gathering, transmission, or distribution. Gathering lines transport gas from a current production facility to a transmission line or processing facility; transmission lines transport gas to distribution centers, storage facilities, or large volume customers; and distribution service lines transport gas to end users [17].

The diverse and segmented nature of underground facilities is evident from the variety of organizational interests that work with the subsurface infrastructure:

- Facility owners design, install, and maintain the underground network..Owners are a diverse group with varied interests; they include private.corporations, municipal public works systems, private and public utility.companies, telecommunication providers, and State transportation traffic.control systems.
- Construction crews engage in excavation activities for a variety of reasons, and they use an assortment of government permits. Excavation activities are carried out by building trades, farmers, homeowners, State and local transportation departments, and others.

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- States regulate actions to protect safety.
- Insurance companies insure the underground facilities, property, and construction business activities.
- Locators work at excavation sites to identify and mark underground facilities. This work may be conducted by the operators of the underground facility or by locating contractors who specialize in providing underground locating services.
- One-call communication centers coordinate notifications about digging activities. These centers may be an operating unit of a facility owner or they may be independent entities that provide notification service to several facility owners.

The number of times people dig into the underground infrastructure illustrates the sheer frequency of excavation: there were an estimated 13 million excavation notices issued to utility operators across the United States in 1996, though the actual number is higher because some excavators do not use one-call notification services [18].

Urbanization of lands through which utility lines are routed, combined with an increase in the number of users of the underground, has created competition for the underground space. A recent study by the American Farmland Trust states that the rate of farmland lost to development is 2 acres per minute, or 1 million acres per year (0.81 hectare per minute, or 405 000 hectares per year) Increased construction activity, which results in increased excavation, is directly related to population growth, demographic shifts, and a growing national economy [19]. New building construction requires that additional services—more utility lines and communication services—be placed in the underground. There is also a trend in current suburban development to remove aboveground utilities to reduce clutter and storm damage. Additions to the underground infrastructure are installed within the underground space occupied by the existing systems. Thus, increased construction can be considered a corollary of increased excavation. This relationship affects the approach to excavation damage prevention because the desire to avoid damage is a genuine interest of everyone, but the success of damage prevention depends on systematic safeguards.

REGULATORY AND LEGISLATIVE INITIATIVES

Underground facilities and pipelines are addressed by various Federal regulations. The Federal regulations issued by RSPA are contained in Title 49 Code of Federal Regulations (49 CFR) Parts 190-199. Parts 191 and 192 address natural gas regulations; Part 195 covers hazardous liquids and carbon dioxide; and Part 198 prescribes regulations for grants to aid State safety programs. Federal regulations establishing minimum standards for excavation damage prevention programs for gas pipeline operators (49 CFR 192.614) were extended to the operators of hazardous liquid pipelines (49 CFR 195.442) effective April 1995 [20, 21].

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Federal regulations mandate companies to develop and participate in damage prevention.programs when those companies transport gas and hazardous liquids subject to DOT jurisdiction [22]. Participation in a one-call notification system satisfies parts of this requirement; consequently, one-call centers have become a key element in damage prevention programs. As the Safety Board's accident investigations and 1994 workshop have pointed out, however, one-call notification programs do not ensure damage prevention. Protection from excavation damage will occur only when facility owners, excavators, locators, and one-call operators—people working with the underground facilities—share responsibilities to protect underground facilities from excavation damage. (These responsibilities are discussed in the next two chapters.)

Both government and industry have, in the past, prepared model statutes that would serve as a framework for individual State legislation of damage prevention programs. The Office of Pipeline Safety Operations (OPSO) prepared model statutes in 1974 and 1977 and encouraged State and local governments to enact model legislation [23]. The APWA prepared guidelines for damage prevention laws that were not substantially different from the OPSO model. The AGA also developed elements for damage prevention legislation; these elements were documented in a 1988 report issued by the Transportation Research Board [24]. Several features of the OPSO model statute overlapped with features in regulations issued by the Occupational Safety and Health Administration.(OSHA) of the Department of Labor.

OSHA regulations require excavators to notify utility owners of planned excavation and to request that the estimated location of underground facilities be marked prior to the start of excavation (29 CFR 1926.651(b)). The regulations also require excavators to determine the exact location "by safe and acceptable means" when they approach the estimated location during excavation [25].

Model legislation was introduced in the 103 d Congress following the 1994 accident in Edison, New Jersey [26]. That bill, which strongly recommended rather than mandated State participation in onecall systems, passed the House of Representatives but not the U.S. Senate. A different version of the bill (HR431/S164) was introduced in, but not adopted by the 104 th Congress. Industry representatives worked with the 105 th Congress.to again develop legislation. The Comprehensive One-Call Notification Act of 1997 (S1115) was introduced into the Senate in July 1997, and the Surface Transportation Safety Act of 1997 (HR1720) was introduced into the House in May 1997. The Senate Committee on Commerce, Science, and Transportation held a public hearing on S1115 in September 1997; the Senate passed the measure on November 9, 1997. The issues related.to the currently proposed legislation are not substantially different from earlier versions; a comparison of the features indicates the following:

- The current bills are advisory in nature rather than prescriptive.
- The House bill recommends participation by all facility owners and excavators; the Senate bill recommends appropriate participation by underground facility operators and excavators. Both contain incentives for.compliance based on providing grant monies for State use.

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- Both bills recommend general components to be included in the State programs; the House bill calls these elements, the Senate bill calls them minimum standards. There is no specific guidance for States concerning the organizational structure and funding mechanisms of one-call centers, or the administration of enforcement provisions.
- Both bills include a mechanism for recommending effective damage prevention practices; specifically, the Secretary of Transportation shall study existing one-call systems to determine practices that are most effective in preventing excavation damage.

The recently introduced legislation makes no specific requirements on the States because the Federal government has not exercised jurisdiction over one-call operations, and because States cannot be required to pass legislation. This has led one industry trade publication to characterize both bills as "toothless in terms of being able to require states, excavators, facility operators, or one-call centers" to modify existing practices to achieve the objectives set forth in the legislation [27]. Table 12.1 shows a comparison of the two bills that appeared in a recent trade association newsletter. The Safety Board's position regarding certain provisions of the proposed legislation is discussed in the next chapter.

House Bill HR1720	Senate Bill S1115[a]
1. Shall consider the establishment of a nationwide toll-free telephone number system. 2. Elements of a State program shall include: (a) All excavators and facility operators; (b) 24-hour coverage for emergency notice; (c) Public education about the program; (d) Proper excavation procedures training; (e) Excavators must contact the One-Call Center; (f) Facility operators must mark their facilites; (g) Effective enforcement; (h) Fair free schedule for operating the State program. 3. Funding of $1M in fiscal year 1998, "as necessary" in FY 1999, and 2000 to be used for improving damage prevention. Money to come from fees collected from pipeline operators. 4. Secretary of Transportation to develop a model program in consultation with all affected parties, conduct workshops and public education.	1. (Telephone number language deleted because OCSI already has a system in operation.) 2. Minimum standards of a State program to include: (a) appropriate participation by excavators and facility operators considering risks, cost: benefit ratios, and allowing voluntary participation where risk is low; (b) Administrative system of variable penalties. 3. Funding of: (a) grants of $1M in FY 1999 and $5 M in FY 2000 to be available until expended; (b) funds "as necessary" in FY 1998–2000 for administration. Money to come from general revenues. States would get money when the Secretary of Transportation has determined, from a grant application, that the State is in compliance with the minimum program standards. 4. Secretary to review the one-call system "best practices" and issue a report.

[a] The U.S. Senate passed S1115 on November 9, 1997.

Source: The Conduit 3(4): 1, 4. August 1997. Spooner, WI: National Utility Locating Contractors Association. (The full text of the bills is available on the Internet at www.underspace.com.)

FIGURE 12.1 Comparison by a trade association newsletter of the currently proposed federal legislation for one-call systems.

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DAMAGE PREVENTION PRACTICES

In its report of the accident in Allentown, Pennsylvania, on June 9, 1994, the Safety Board highlighted the common elements of effective State excavation damage prevention programs that have been recognized in the industry and that were discussed in detail at the Safety Board's 1994 workshop [28]. The elements include:

1. Mandatory participation by all affected parties, whether private or public
2. A true one-call notification system in which excavators can alert all operators of buried systems
3. Swift, effective sanctions against violators of State damage prevention laws
4. An effective education program for the public, contractors, excavation machine operators, and operators of underground systems that stresses the importance of notifying before excavating, accurately marking buried facilities, and protecting marked facilities when excavating.

Other elements that have been deemed critical to an effective damage prevention program and that have been the subject of past Safety Board recommendations include accurate mapping, employee training, and emergency response planning. This chapter discusses the various aspects of these elements and summarizes the reports and conclusions of the 1994 workshop participants as they relate to these elements.

MANDATORY PARTICIPATION

Every State except Hawaii and the District of Columbia has a damage prevention law to govern the activities of operators and excavators of most buried facilities. Texas, the most recent State to enact legislation, passed the Underground Facility Damage Prevention and Safety Act in June 1997 to establish a non-profit corporation to oversee the State's three one-call systems. The Governor of Puerto Rico is preparing damage prevention legislation for introduction in the Legislative Assembly. In the interim, he has issued an Executive Order that establishes an excavations notice center, requires government facility operators to use the center, and encourages its use by private entities.

Individual States have developed a variety of program approaches to handling the problem of excavation damage of underground facilities. A key finding in a 1995 OPS study was that there were "significant variations among state statutes, among excavators, and among facility operators in the ways that excavation around underground facilities is done " [29]. Table 12.2 provides an overview of the variations among State programs.

More than half the States (30) have mandatory one-call participation programs and most (39) are intended to protect all utilities. However, all but seven States (Connecticut, Iowa, Massachusetts, Maryland, Maine, New Hampshire, and Vermont) have granted exemptions to a variety of organizations. State laws

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Overview of the characteristics of State programs to prevent excavation damage.

Program characteristic	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Con-necticut	Delaware	District of Columbia	Florida	Georgia	Hawaii	Idaho
Protects all utilities[a]	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Mandatory participation for facility owners			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
No exemptions for excavation notification							✓						
24-hour access[b]						✓	✓						
Emergency response procedures	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Permits issued		✓			✓				✓				
Penalty clause	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Notification time 2 days or less		✓				✓				✓			
Positive response			✓	✓	✓		✓	✓	✓	✓			✓
Standard marking color code	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Tolerance zone within 24 inches	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Year of State legislation	1994	1987	1995	1995	1984	1993	1987	1979	1979	1997	1986		1991
Legislative activity in 1997						✓				✓	✓		
Number of one-call service centers	1	1	1	1	2	1	1	1	1	1	1		6

FIGURE 12.2 Overview of the characteristics of state programs to prevent excavation damage.

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Overview of the characteristics of State programs to prevent excavation damage.

Program characteristic	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine	Maryland	Massa-chusetts	Michigan	Minne-sota	Missis-sippi	Missouri
Protects all utilities[a]	✓		✓		✓	✓		✓		✓	✓	✓	✓
Mandatory participation for facility owners	✓		✓	✓		✓	✓	✓	✓	✓	✓		
No exemptions for excavation notification			✓				✓	✓	✓			✓	
24-hour access[b]	✓	✓	✓	✓			✓		✓	✓	✓		✓
Emergency response procedures	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Permits issued							✓		✓				
Penalty clause	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Notification time 2 days or less	✓	✓	✓		✓		✓	✓			✓	✓	✓
Positive response	✓	✓	✓	✓		✓		✓		✓		✓	✓
Standard marking color code	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Tolerance zone within 24 inches	✓	✓	✓	✓	✓	✓		✓		✓	✓		
Year of State legislation	1991	1990	1993	1993	1995	1995	1991	1974	1980	1989	1987	1985	1992
Legislative activity in 1997	✓		✓								✓	✓	
Number of one-call service centers	2	1	1	1	1	1	1	2	1	1	1	1	1

FIGURE 12.2 *continued* Overview of the characteristics of state programs to prevent excavation damage.

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Overview of the characteristics of State programs to prevent excavation damage.

Program characteristic	Montana	Nebraska	Nevada	New Hamp-shire	New Jersey	New Mexico	New York	North Carolina	North Dakota	Ohio	Oklahoma	Oregon	Pennsyl-vania
Protects all utilities[a]	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
Mandatory participation for facility owners	✓	✓	✓	✓	✓		✓		✓	✓		✓	✓
No exemptions for excavation notification	✓			✓		✓		✓					
24-hour access[b]	✓	✓	✓	✓					✓	✓	✓	✓	✓
Emergency response procedures	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Permits issued				✓					✓				✓
Penalty clause	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓
Notification time 2 days or less	✓					✓			✓				
Positive response	✓	✓	✓		✓		✓		✓		✓	✓	✓
Standard marking color code	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tolerance zone within 24 inches	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓
Year of State legislation	1991	1995	1987	1983	1994	1991	1997	1986	1995	1990	1982	1997	1996
Legislative activity in 1997				✓		✓		✓		✓			
Number of one-call service centers	2	1	1	1	1	2	2	1	1	2	1	1	1

FIGURE 12.2 *continued* Overview of the characteristics of state programs to prevent excavation damage.

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Overview of the characteristics of State programs to prevent excavation damage.

Program characteristic	Rhode Island	South Carolina	South Dakota	Tennes-see	Texas	Utah	Vermont	Virginia	Wash-ington	West Virginia	Wis-consin	Wyoming
Protects all utilities[a]		✓	✓	✓		✓		✓	✓	✓	✓	✓
Mandatory participation for facility owners	✓		✓			✓	✓	✓	✓		✓	✓
No exemptions for excavation notification				✓			✓					
24-hour access[b]	✓		✓	✓	✓		✓			✓		
Emergency response procedures	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Permits issued	✓						✓					✓
Penalty clause	✓	✓		✓		✓	✓	✓	✓		✓	✓
Notification time 2 days or less	✓		✓			✓	✓			✓		✓
Positive response		✓	✓	✓		✓		✓			✓	✓
Standard marking color code	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Tolerance zone within 24 inches	✓			✓	✓	✓	✓	✓	✓	✓		✓
Year of State legislation	1984	1978	1993	1978	1997	1977	1988	1994	1990	1996	1995	1996
Legislative activity in 1997		✓	✓	✓	✓							
Number of one-call service centers	1	1	1	1	3	1	1	3	8	1	1	10

[a] Subject to each State's definition of activity.

[b] Although notification calls may be recorded on a 24-hour basis, most States process notifications only during normal business hours.

Source: One-Call Systems International Directory, 1997–1998. The criteria identified for program characteristics were taken from the proceedings of the National Transportation Safety Board's workshop held in 1994 (NTSB/RP-95/01).

FIGURE 12.2 *continued* Overview of the characteristics of state programs to prevent excavation damage.

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specifically qualify their exemptions, but, in general, exempt organizations are not required to participate in the State's excavation damage prevention program. Exemptions have been granted to State transportation departments, railroads, mining operations, city/State/Federal governments, cemeteries, water utilities, military bases, and Native American Lands. Although underground facilities frequently follow road rights-of-way, nine States have current damage prevention legislation that specifically exempts State transportation departments; another dozen States exempt substantial State highway maintenance activities. State highway administrators have argued that they do not have the resources for participating in notification and marking. Several States (Arizona, Arkansas, Delaware, Oregon, Mississippi, and Washington) exempt agricultural activities, home owners, and tilling operations less than 12 inches (30.5 centimeters) deep. By receiving exemptions, these entities are not required to inform utilities or underground facility owners of their digging activities, nor are the underground facilities operated by these exempt entities marked or protected in advance of scheduled excavations.

In the 1994 Green River, Wyoming, accident investigated by the Safety Board, a highway contractor operating excavation equipment struck a 10-inch-diameter natural gas gathering line [30]. The accident resulted in three fatalities. The pipeline operator did not participate in the local excavation notification one-call program, though the operator was required by the State of Wyoming to belong to the one-call system. The highway contractor notified the one-call center prior to excavation but did not notify one-call concerning project modifications that expanded the geographic area of work. Neither the Wyoming Department of Transportation nor its contractor made telephone notification directly to the pipeline operator. Had these parties participated in the one-call notification program, the gas line would have been marked and the accident likely would not have happened.

In April 1996, excavation damage of a water main in Buffalo, New York, flooded the downtown area. The municipal water department was not a member of the local one-call system. In fact, at that time four separate city utilities in Buffalo had to be notified to coordinate excavation work; none of those utilities participated in the local one-call system. This situation existed even though State law required participation and made it free for municipalities.

Panelists at the 1994 damage prevention workshop agreed that all owners/operators of buried facilities should participate in damage prevention programs; there should be no exceptions. Some States have realized the value of full participation and have taken legislative action to ensure participation. For example, according to Pennsylvania law, underground facility owners who are not one-call members cannot collect damage costs from excavators who hit their lines. A similar requirement became effective in Florida in October 1997. Oregon has mandatory one-call membership provisions for all facility owners with lines that cross public rights-of-way [31].

The Safety Board agrees that the failure of all parties to participate in damage prevention programs can substantially undermine the effectiveness of the programs. When parties such as State transportation departments and railroads are

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given exemptions to participation in excavation damage prevention programs, these parties, in essence, are no longer obligated to use one-call notification centers to protect their facilities or to protect the facilities of others that use their rights-of-way. Nor are they obligated to inform other parties of their intent to dig or excavate. In addition to public safety interests, the Board is concerned that taxpayers ultimately bear the burden for these exemptions by paying for the cost of fixing excavation damage, particularly damage caused by State agencies that are not protecting their facilities. The Safety Board concludes that full participation in excavation damage prevention programs by all excavators and underground facility owners is essential to achieve optimum effectiveness of these programs.

Because of the number of State transportation department activities that are exempt from participating in excavation damage prevention programs, the Safety Board believes that the Federal Highway Administration should require State transportation departments to participate in excavation damage prevention programs and consider withholding funds to States if they do not fully participate in these programs.

Although railroad rights-of-way are not as prevalent as those of highways, they frequently serve as ideal routes for underground facilities, particularly for gas and oil transmission lines. Contractual provisions for underground facilities to use railroad rights-of-way are a revenue source for the railroads. However, railroads are also exempt from participating in some State excavation damage prevention programs. For the larger, Class 1 railroads, there are usually internal operating procedures for notification of excavation work on railroad property. However, recent trends in contracting out construction and maintenance services suggest that not all work is controlled through internal operations. Additionally, the number of small, short line railroad companies is increasing. The Association of American Railroads estimates that there are 450–475 short line railroads; 424 are members of the American Short Line Railroad Association (ASLRA). ASLRA membership has doubled in the past 25 years. These smaller companies often do not have the resources to operate internal excavation notification systems. Consequently, the Safety Board believes that the Association of American Railroads and the American Short Line Railroad Association should urge their members to fully participate in statewide excavation damage prevention programs, including one-call notification centers.

ONE-CALL NOTIFICATION SYSTEM

Function and Structure of the Centers

A cornerstone of current damage prevention programs involves the use of one-call notification centers. One-call notification centers function as communication systems established by two or more utilities, government agencies, or other operators of underground facilities to provide one telephone number for notification of excavating, tunneling, demolition, or any other similar work [32]. The system is

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designed so that excavation contractors, other facility owners, or the general public can notify the one-call center of the location of intended digging or construction activity. The intended area of excavation may be premarked, generally with white spray paint, to specifically indicate the digging or construction area [33]. Based on that one call, the center, in turn, notifies its members that digging or construction will occur in a given location. The facility owners, or their contract locator service, go to the excavation site and mark the location of any of their underground facilities in that area. By avoiding the use of power-driven tools in the vicinity of marked facilities, there is a decreased risk of damage to underground facilities.

Notification services use a variety of names and logos to create meaningful associations in the public's mind: Miss Dig System in Michigan, Underground Service Alert in California, Utility Protection Center in Georgia, and Digger for the Chicago Utility Alert Network. There are 84 one-call centers in the U.S. covering almost all areas of the country [34]. Of these, 55 are members of One-Call Systems International (OSCI). OSCI members recorded over 13 million excavation notifications in 1996 [35].

In 1996, a nationwide referral number, 1-888-258-0808, was established by the APWA and administered by Sprint. In the fall of 1997, this number was automated by the APWA and is handled through the Georgia One-Call Center. A placard containing this number is placed on all newly manufactured construction equipment; placarding resulted from coordination with the Equipment Manufacturers Institute. Ideally, a call to that nationwide referral number would result in an automatic transfer to the appropriate one-call center. This automatic transfer exists on a small scale for the State of California, which uses two one-call systems but uses only one statewide phone number. However, because automated switching of calls to the referral number would result in substantial expenses for long distance telephone charges and billing, the existing referral service informs the caller of the correct one-call number, based on the caller's identification of the geographic location of the excavation, and the caller must then place a second phone call to that center.

The organizational structure of one-call centers varies: some are functioning units of the local ULCC; others are joint efforts of a few facility owners. Statutory language in some States stipulates the composition of the Board of Directors (for example, Minnesota, North Dakota, South Dakota, Nebraska, and Oregon), but government involvement varies by State and by one-call center [36]. Many one-call centers have been organized as not-for-profit corporations that operate with a limited degree of State oversight. Their administrative framework, funding arrangements, and operating procedures also vary. For example, California allows local government agencies to recover all costs of one-call membership through the permit fees that it charges contractors. Several States make participation by municipalities free. According to the OCSI, its member organizations were "developed to best suit the needs of the underground facility owners in that state" and "state laws do not govern the operation of a one-call system. The laws generally set out who is required to belong to a one-call system and who must call a one-call system as well as enforcement provisions. No two State laws are alike" [37].

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Methods of Operation

The differences in State involvement translate into very practical distinctions between one-call centers. An assortment of communication methods are used to receive excavators' calls and to issue notification tickets to the centers' participants; centers may use telephone staff operators, voice recorded messages, e-mail, fax machines, Internet bulletin boards, or a combination of methods. Service hours may be seasonally limited to a few hours a day or extend to 24 hours a day. Some locations operate only seasonally because of construction demand; most operate year-round. Most centers have statewide coverage but may not strictly follow State boundaries. A center may cover portions of several States (Miss Utility in Virginia, Maryland, and the District of Columbia) or there may be several centers within a State (Idaho has six different one-call systems; Washington and Wyoming each have nine). Centers may provide training to the construction community, conduct publicity campaigns to educate the public to excavation notification requirements, and work with facility operators to protect their underground facilities. Other centers do little work in these areas.

Some centers use positive response procedures—members who do not mark facilities in the construction area confirm that they have no facilities in the area rather than just not mark a location; other centers do not have this requirement. A part of the Miss Utility program in the Richmond, Virginia, area uses positive response procedures to notify the excavator when the marking is complete. Facility owners directly inform a voice messaging system of the status of a notification ticket. (Notification tickets are identified and discussed in the following section.) As a timesaving alternative, the contractor can call the information system anytime to receive an up-to-date status of their marking request. Information indicating that marking has been completed, or that no facilities are located in the area of excavation, allows construction work to proceed as soon as marking is completed rather than waiting the full time period for which marking activity is allowed.

The important elements of an effective one-call notification center have been generally identified by industry organizations. For example, the position of the Associated General Contractors of America on one-call systems is summarized in six elements: mandatory participation; statewide coverage; 48-hour marking response; standard marking requirements; continuing education; and a fair system of liability [38]. Participants at the Safety Board's 1994 workshop, on the other hand, developed detailed lists of elements they believed are essential for an effective one-call notification center, other elements a center should have, and elements it could have. All agreed, however, that first and foremost was the need for mandatory participation and use of notification centers by all parties. The Safety Board concludes that many essential elements and activities of a one-call notification center have been identified but have not been uniformly implemented.

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Excavation Notification Tickets

A record of a locate request is generally called an excavation notification ticket, but there is no standard format for one-call excavation notification tickets. One-call centers track excavation activity based on the number of notification tickets they handle for their members, but they do not necessarily track how many of those digging activities result in excavation hits. For the centers that do maintain a record of hits, one-call members must report their hits to the center; the center then compiles the information.

The OCSI Committee on Communication Standards is developing a universal ticket format to address the problem of underground facility owners who work in different States and who receive tickets from more than one notification center [39]. For large companies working in different one-call areas, information that is organized into different formats can be confusing and can lead to unsafe activities at the excavation site. According to discussions at the Safety Board's 1994 workshop, the format needs to be consistent between centers, both in terms of ticket information and the work unit represented by a ticket. For example, a ticket from one center might encompass work for all utilities at a given two-block construction site, whereas another might separate tickets for each utility, or by smaller geographic areas. Damage reports must also be consistent, and OCSI is considering the feasibility of including damage information in the universal ticket format. The committee expects to finalize a universal ticket format in January 1998. The Safety Board encourages the OCSI members and all other notification centers to adopt a universal ticket format and to maintain ticket data. Standard ticket information would be an essential first step in developing performance measures for damage prevention programs.

EFFECTIVE SANCTIONS

Penalties for failure to act in accordance with State damage prevention programs vary depending on location; provisions for oversight and timely enforcement can be quite different from State to State. Administrative enforcement of State excavation damage prevention laws does not require State court actions and has been shown to be effective in several States. For example, in Pennsylvania's new legislation (Act 187 enacted in 1996), the process of enforcement includes $100 and $200 citations for minor infractions to the State's excavation damage prevention law and $2,500 and $25,000 civil penalties for more serious infractions. The Department of Labor and Industry is responsible for administrative enforcement; the State's Attorney General handles civil penalties.

The use of administrative enforcement is a characteristic of several State programs for excavation damage prevention. The following examples from Massachusetts, Minnesota, and Connecticut illustrate three programs that operate differently but use administrative enforcement to effect safer excavation practices.

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The structure and cost of penalties for nonparticipation in the excavation damage prevention programs varies, but the States' common goal is to foster safe practices.

Massachusetts originally passed damage prevention legislation in 1959; it required all excavators to notify utilities before they began to dig. Legislation in 1980 empowered the Department of Public Utilities (DPU) with enforcement authority under the State's Administrative Procedures Act. Beginning in 1986, the Dig Safe Law enforcement was delegated to the chief engineer in the pipeline engineering and safety division of the DPU. A staff of one person handles the administrative enforcement of damage prevention for the State of Massachusetts. That person has authority to issue notices of probable violation with fines that range from $200 to $1,000. In administering the program, the DPU keeps fines at a reasonable level compared to many other States. Since 1986, the State has issued over 3,000 notices; third-party damages dropped from 1,138 in 1986 to 412 in 1993. The Department requires utility companies to report any third party damages within 30 days, and excavators are encouraged to send the Department violation notices for State adjudication if they find fault with the utility companies. State utility owners and excavators are provided books of violation tickets to document infractions of damage prevention rules to the DPU. Using this mechanism, involved parties can notify the State of problems, such as when facilities are mismarked or not marked within the required time, when excavators do not use the notification system, or when line hits are not reported. The State has found that its readiness to dispense small penalties has resulted in awareness of damage prevention throughout the industry. The State's administrative enforcement process does not rely on the Attorney General's office for execution; thus it keeps State pipeline safety actions from being in direct competition with all other State actions.

Other States have also found benefits from administrative rather than court enforcement of their regulations. Minnesota's Department of Public Safety, Office of Pipeline Safety, takes complaints, investigates, and issues penalties of up to $500. The State Office of Pipeline Safety, MnOPS, is the enforcement entity. Minnesota focuses strongly on education as a key to the success of damage prevention. Violators of the regulation often are allowed to institute training actions instead of paying fines.

Connecticut also uses an administrative process to enforce its damage prevention program. Its Call-Before-You-Dig law, first passed in 1978, had only one penalty provision: if an excavator failed to call before digging and subsequently damaged facilities, the excavator could be fined up to $10,000. A representative from Connecticut Call Before You Dig has stated, however, because of the severity, the penalty was not used [40]. An accident on December 6, 1985, in Derby, Connecticut, occurred when an excavator struck a gas line; the excavator had used the notification system [41]. Natural gas from the broken main migrated into the basement of a restaurant, exploded, and killed seven people. The severity of this accident focused attention on the shortcomings of the existing law and resulted in a change in the penalties, fines, and overall structure for enforcement. Connecticut created a position of compliance supervisor, an employee of the one-

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call center, who serves as a field investigator and expert witness at that State's DPU hearings. The compliance supervisor receives incident reports and maintains case files on noncompliance. Connecticut law allows for fines on the first or second offense if the severity of the offense, injuries, or past performance warrants. Otherwise, the compliance supervisor sends a letter to the party explaining the damage prevention program and stating what compliance actions are needed. The DPU may send letters of inquiry or interrogatories, proceed with a docket for penalties, or schedule a "show cause" hearing. Offending parties have 30 days to appeal by requesting a hearing. In 1994, excavation damage to underground lines in Connecticut declined 28.5 percent compared to earlier years before administrative enforcement. Of the 436 incidents of damage in that year, 223 were gas lines, 91 were water lines, 78 were electric lines, 40 were communication lines, and 4 were sewer lines [42].

Other States have implemented stringent programs for excavation damage prevention, with severe penalties for noncompliance. Because of its small area and concentrated population, New Jersey has a dense network of pipelines: 30,000 miles (48 270 kilometers) of intrastate lines and 1,000 miles (1609 kilometers) of interstate lines [43]. As a result of the 1994 accident in Edison, New Jersey, the State implemented heavy fines and strong enforcement, effective in 1995. Digging near a gas line without calling for the facility owner to mark the location can result in a $25,000 fine, and the company involved in underground facility damage is required to provide a written plan for remediation and training. The number of one-call notifications has increased 30 percent between 1995 and 1996. The New Jersey Board of Public Utilities recorded 2.2 million notifications for 1996. Even though there were 17 percent fewer hits in 1996, they still totaled 3,961. As previously mentioned, however, the New Jersey State Department of Transportation is exempt from participating in the one-call notification process.

Participants at the Safety Board's 1994 workshop generally agreed that penalties need to be enforced in order to recover the costs of the damage prevention programs; however, the participants also believed that self-policing partnerships between operators and excavators were essential and that the administration of the program should be as simple and streamlined as possible with a minimum of government oversight. The participants believed that by doing so, costs to stakeholders would be minimized and there would be a greater potential for success. The participants also indicated that State programs should have enough flexibility to be able to implement alternative procedures that still meet the intent of the program.

The administrative approach to enforcement of damage prevention programs is designed to promote compliance rather than punishment, and to create awareness of good damage prevention practices rather than to collect fines or to put small companies out of business. Administrative enforcement has been accomplished without creating an additional bureaucracy, and the cost of the enforcement program has been covered even with the small fines and penalties that are imposed. The Safety Board concludes that administrative enforcement has proven effective in some State excavation damage prevention programs.

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Excavation Marking

Excavation occurs frequently. The excavation notification system in Illinois recorded over 100,000 calls during the month of April 1997 [44]. In New Jersey, its one-call system records 2.2 million excavation markings per year, an average of more than 6,000 per day [45]. With this rate of occurrence, the frequency of hits would be dramatically higher if some information about line locations were not available.

An entire industry of underground utility locating businesses have developed in the last two decades. Primarily, these businesses serve utility companies by performing the marking services associated with one-call notification. Referred to as locators, these technicians visit construction sites and mark the location of underground facilities using both mapping technology and electronic tools. Practices for marking the underground facilities can have an impact on the risk of excavation damage. Good practices include pre-marking the intended excavation site by the excavator to clearly identify to the facility locator the area of digging; positive response by the utility owner to confirm that underground facilities have been marked or to verify that no marking was necessary; the use of industry-accepted marking standards to unambiguously communicate the type of facility and its location; marking facility locations within the specified notification time; and responding to requests for emergency markings, when necessary.

The timeframe for excavation marking is usually specified by State damage prevention laws. Twenty States require underground facility marking to be accomplished within 48 hours of excavation notification. Construction work planning is not evenly distributed throughout the week; consequently, one-call centers may schedule three or four times the number of locates for some days compared to other days. This, in turn, creates variable workloads for utility locators.

Pre-Marking. Participants at the 1994 workshop agreed that pre-marking the proposed excavation area has been demonstrated to enhance the safety of excavation activities. Pre-marking allows the excavators to specifically tell facility owners where they intend to dig. Some States require the use of white marking to indicate the boundaries of planned excavations. Maine was one of the first States to have mandatory pre-marking for non-emergency excavations. Connecticut has also adopted a pre-marking requirement; the law provides for face-to-face meetings between operators and excavators for projects that are too large for or not conducive to pre-marking.

According to workshop participants, pre-marking an excavation site helps to ensure that owners of underground facilities are aware of the specific area that is to be excavated. Facility owners avoid unnecessary work locating underground facilities that are not associated with the planned excavation. Excavators can be certain that underground facilities within their intended area of excavation are well marked. Because pre-marking defines the physical boundary of the excavation site, it removes ambiguity about what underground facilities need to be located. Marking the intended excavation area creates a greater likelihood that

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affected underground facilities will be identified to the excavator. The Safety Board concludes that pre-marking an intended excavation site to specifically indicate the area where underground facilities need to be identified is a practice that helps prevent excavation damage.

Marking Standards. Most State laws on damage prevention call for facility owners to follow the standards for temporary marking developed by the ULCC. Figure 12.1 identifies the color codes. Local one-call centers often distribute pocket-size flash cards with these color codes to excavators. The use of standard marking colors informs the excavator about the type of underground facility whose location has been marked.

Markings of the appropriate color for each facility are placed directly over the centerline of the pipe, conduit, cable, or other feature. There are procedures for offset markings when direct marking cannot be accomplished. For most surfaces, including paved surfaces, spray paint is used for markings; however, stakes or flags may be used if necessary. In addition to uniform color codes used to transmit standard information about the type of facility marked, the National Utility Locating Contractors Association (NULCA) has developed a proposal for standard marking symbols. The proposal is currently available only for internal use but is being designed for distribution to members in the future. NULCA's proposed standard addresses conventions for marking the width of the facility, change of direction, termination points, and multiple lines within the same trench. The standard symbology indicates how to mark construction sites to ensure that excavators know important facts about the underground facilities; for example, hand-dig areas, multiple lines in the same trench, and line termination points. The Safety Board recognizes the benefit of industry efforts to standardize marking practices. Such conventions help to avoid misinterpretation between locators who designate the position of underground facilities and excavators who work around those facilities. Participants at the workshop recommended that uniform marking include the facility owners' identification.

NULCA's work to define standard marking symbols incorporates the use of facility owner's identification marks along with conventions for identifying underground system configurations.

EMPLOYEE QUALIFICATIONS AND TRAINING

Training to prevent excavation damage to the underground infrastructure is not limited to the pipeline industry and operating personnel: locators need training in locating techniques, equipment technology, and marking procedures; excavators need training to fully participate in the notification process and to understand locator marking symbols; one-call operators need training to efficiently and effectively transmit information between excavators and underground system operators; and the general public needs to be aware of the one-call notification process when they dig for private projects. In addition, anyone working to oper-

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Color	Feature identified
red	electric power lines, cables, conduit and lighting cables
yellow	gas, oil, steam, petroleum, gaseous materials
orange	communications, alarm or signal lines, cable or conduit
blue	water, irrigation, and slurry lines
green	sewers, drain lines
pink	temporary survey markings
purple	cable television
white	proposed excavation

FIGURE 12.3 Uniform color code of the American Public Works Association, Utility Location and Coordinating Council.

ate underground systems or whose work requires underground digging needs to be trained in emergency response procedures. This diversity of training needs presents a challenge to both system regulators and the industry.

Training and Educating Excavation Personnel. Excavators need to be trained and educated about safe work conditions, good excavation practices, relevant State laws, and one-call procedures. In this context, the excavator is not only the backhoe operator at the construction site, but also the project manager, the scheduler, company officials—anyone connected to excavation work. In an effort to ensure that excavators are aware of their responsibilities to protect underground facilities, some States have licensing requirements that assess professional knowledge. For example, Florida law (in Section 556.104 of the Florida Statutes) requires contractors who work near buried facilities to be licensed, a process that involves passing a written examination. Excavators should fully understand the one-call notification process: the meaning of facility markings, requirements for hand digging near underground facilities, notification responsibilities when the scope of work changes, and emergency response procedures. Many one-call centers offer outreach training programs designed for excavators. Some one-call center personnel have met with local union organizations and industry associations to explain the notification process and State damage prevention laws.

Because marking the position of an underground line is a safety-critical job, training is necessary to ensure that locators are well prepared to perform this function. NULCA has defined a set of minimum standards for its members to adopt as part of their training programs [46]. The program includes 118 hours of structured training in the topics of system design, construction standards, equip-

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ment techniques, recognition of line type, locating theory, and safety procedures. In addition to recommending the use of written tests, the program recommends field training and annual retesting.

The NULCA has also developed guidelines for excavation practices and procedures for damage prevention. These guidelines, which were revised in September 1997, incorporate OSHA requirements and identify best practices applicable to excavation work. Use of the guidelines is voluntary, but NULCA's brochure explains that legislation in most States requires contractors who plan to excavate to notify the appropriate one-call center and non-member facility owners before the job begins. The guidelines address preplanning and job site activities for both large and small projects. Instructions for handling damage, along with a construction facility damage report form, are also included. The Safety Board commends NULCA's efforts in promulgating good practices among its members and the excavation community.

Title 29 CFR 1926, Subpart P, contains several worker safety requirements on excavation activities. In 1990, OSHA developed and issued a booklet, Excavation, to assist excavation firms and contractors in protecting workers from excavation hazards. The booklet is based on the requirements of Part 1926 and gives specific advice on preventing cave-ins and providing protective support systems. OSHA employs several methods of providing information to persons subject to its regulations; its latest information system uses the Internet via the World Wide Web to provide assistance to excavators and contractors on complying with OSHA requirements. Responses to frequently asked questions, statistical data, news releases, OSHA pamphlets and publications, and a listing of available training materials can be obtained via the computer.

Federal training requirements for the transport of hazardous liquids are stated in 49 CFR 195.403. These are general requirements that do not specifically discuss excavation activities, and there are no comparable general training requirements for gas operator employees. RSPA has a joint industry and government working group that periodically meets to develop proposed requirements for employee qualification and training. That committee, the Negotiated Rulemaking Advisory Committee on Pipeline Personnel Qualifications, completed its fourth meeting in August 1997. It has prepared three drafts of a proposed operator qualification regulation for committee consideration. The committee has not reached consensus and is still considering draft regulatory language.

Participants at the Safety Board's workshop recommended that excavator associations work in conjunction with operators of buried facilities and one-call notification centers to provide buried-facility damage-prevention training as part of their safety training programs. The participants acknowledged that the Associated General Contractors of America and many contractor organizations are very safety conscious and have produced several videotapes about safety issues. Few of these education efforts, however, include testing. The current negotiated regulation process at RSPA has addressed the issue of training verification and testing, but the scope of that work is limited to only oil and gas operators subject to Federal regulations.

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The Safety Board has long been concerned that all personnel involved in excavation activity be properly trained and qualified and has issued several recommendations in this area as a result of its accident investigations. Following the investigation of an accident in Derby, Connecticut, in December 1985, the Safety Board recommended that Northeast Utility Service Company

> *Emphasize in its training of operating personnel the importance of following the company procedures for patrolling and protecting its gas mains in proximity to excavation projects. (P-86-19) [47].*

The Safety Board's investigation of an accident that occurred 3 months later in Chicago Heights, Illinois, also generated a recommendation concerning training. The Board recommended that Northern Illinois Gas Company

> *Emphasize in company training the importance of following company procedures for making areas near gas pipeline leaks safe for the public by evacuation or other means. (P-87-38) [48].*

As a result of an explosion and gas-fueled fire that occurred on July 22, 1993, when a backhoe of the city of St. Paul Department of Public Works hooked and pulled apart a high-pressure gas service line, the Safety Board asked the American Public Works Association to

> *Advise its members of the circumstances of the July 22, 1993, explosion in St. Paul, Minnesota, and urge them to develop and implement written procedures and training to prevent excavation-caused pipeline damages. (P-95-24) [49].*

In 1987, RSPA first issued a notice of proposed rulemaking (NPRM) to improve the competency of operator personnel and to set minimum training and testing standards for employees of pipeline operators. A notice issued in October 1991 stated that a second proposal, based on comments received earlier, would be forthcoming. By 1993, RSPA still had not acted to implement any employee qualification and testing standards, and the Safety Board urged that this issue become a priority in the regulatory agenda. Ten years after its original NPRM in 1987, RSPA has entered into negotiated rulemaking. Action on this issue is long overdue. The Safety Board concludes that employee qualification and training is an integral component of an effective excavation damage prevention program, and industry has recognized the need for employee training but has not implemented training uniformly. Inadequate employee training was highlighted in the Safety Board's report of the San Juan accident [50]. In that report, the Board recommended (P-97- 7) that RSPA complete a final rule on operator employee qualification, training, and testing standards within 1 year. The Board further stated

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in that recommendation that the final rule should require operators to test employees on the safety procedures they are expected to follow and to demonstrate that they can correctly perform the work.

Because RSPA's rulemaking would cover only those employees of oil and gas operators subject to Federal regulations, additional efforts are needed by industry to provide training materials to those employees not covered by the regulations. The OCSI's Training Committee—which develops educational materials for use by notification center employees, facility owners, and excavators—would appear to be the appropriate organization to accomplish this goal. Therefore, the Safety Board believes that the APWA should review existing training programs and materials related to excavation damage prevention and develop guidelines and materials for distribution to one-call notification centers.

Emergency Response Planning. Pipeline operators are required by law to establish written emergency procedures for classifying events that require immediate response, communicating with emergency response officials, and responding to each type of emergency [51]. Although the extent of emergency response planning may vary depending on the type of excavation activity, emergency response planning should involve a definition of responsibilities, a flow chart of actions, execution criteria, systems inventory and resource information, coordination procedures (internal and external), and simulation exercises of response actions.

Federal regulations require no emergency response plan for excavators; however, these are the very people that often have responsibility for first response at an excavation disaster. The Safety Board has addressed the need for emergency response plans and procedures in many of its reports of accidents involving excavation damage. One such accident was an explosion in Cliffwood Beach, New Jersey, on June 9, 1993, that occurred as a result of a utility contractor's trenching operation. The Safety Board's investigation determined that a failure in training was causal to the accident [52]. The utility operator did not brief or determine whether the contractor knew what procedures to follow should the crew damage a main or service line. In addition, the Safety Board found no record or evidence of the contractor being properly trained in emergency procedures, and the facility operator's procedures did not include emergency response training for contractors. As a result of its investigation, the Safety Board recommended that the gas company take the following actions:

> *Train all gas operations construction contractors for emergencies involving struck pipelines; training should stress immediately reporting natural gas pipeline strikes to New Jersey Natural Gas's emergency phone number. (P-94-01) [53].*

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As a result of the previously mentioned accident in St. Paul, Minnesota, on July 22, 1993, the Safety Board recommended that the American Public Works Association

> *Urge your members to call 911 immediately, in addition to calling the gas company, if a natural gas line has been severed. (P-95-25) [54].*

The Safety Board concludes that, at a minimum, excavators should formulate an emergency response plan appropriate for the specific construction site and ensure that employees working at that site know the correct action to take if a buried facility is damaged. The local one-call center can also play an important role in planning with local officials to define the best emergency response appropriate for its communities. The local one-call centers also are in a good position to disseminate this information on a regular basis. Therefore, the Safety Board believes that the APWA should develop guidelines and materials that address initial emergency actions by excavators when buried facilities are damaged and then distribute this information to all one-call notification centers.

Discussion

The Safety Board acknowledges that considerable progress has been made by RSPA and the industry in the area of improving excavation damage prevention programs since the Board's 1994 workshop and most likely because of it. The workshop provided a valuable forum to discuss how government and industry can work together to improve excavation damage prevention programs. The Safety Board believes that by continuing to focus attention on this important safety issue, the number of excavation-caused accidents to the Nation's underground facilities will ultimately decrease. Therefore, the Safety Board believes that RSPA should conduct at regular intervals, joint government and industry workshops on excavation damage prevention that highlight specific safety issues, such as full participation, enforcement, good marking practices, the importance of mapping, and emergency response planning.

Specific progress has been made to standardize marking symbols, to develop a uniform notification ticket, to develop guidelines for excavation practices and procedures, and to develop minimum standards for training programs. The importance of mandatory participation has been advocated by industry as well as government, yet many entities are granted exemptions to participation in State excavation damage prevention programs. Although many elements of an effective State excavation damage prevention program have been identified, the Safety Board is concerned that these elements have not been uniformly implemented. Some States have realized the benefit of swift, effective sanctions through the administrative process, yet many States are lacking effective enforcement programs. The practices and activities of one-call notification centers have also been identified, but these practices have not been uniformly implemented. The Safety

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Board concludes that although considerable progress has been made to improve State excavation damage prevention programs, additional efforts are needed to uniformly develop and implement programs that are most effective.

In 1996, RSPA established a joint government/industry Damage Prevention Quality Action Team. Participants include the American Petroleum Institute (API), the American Gas Association (AGA), the American Public Gas Association (APGA), the Interstate Natural Gas Association of America (INGAA), One-Call Systems International (OCSI) of the APWA, the National Telecommunications Damage Prevention Council, the National Association of Regulatory Utility Commissioners (NARUC), the Associated Electrical and Gas Insurance Services, the National Association of Pipeline Safety Representatives, and industry participants. As stated in its charter, "the purpose of that team is to assess the status of current excavation damage prevention efforts and their effectiveness, and to identify additional efforts that would lead to reduction of excavation damage." However, rather than assessing the status of damage prevention efforts, the group set as its goal to "conduct a national pipeline awareness campaign." As of June 1997, the team had developed and distributed surveys to assess the awareness of one-call systems. Because the critical elements of an effective excavation damage prevention program have not been uniformly implemented at the State level, the Safety Board believes there is a need to review and evaluate existing damage prevention programs and to highlight deficiencies in existing programs so that corrective action can be taken. The Safety Board supports current legislative interest in provisions for a review of existing excavation damage prevention programs but does not believe there is a need to await Congressional action before such an evaluation is undertaken. The Damage Prevention Quality Team appears to be an appropriate mechanism for accomplishing a detailed evaluation of existing programs. Therefore, the Safety Board believes that RSPA, in conjunction with the APWA, should initiate and periodically conduct detailed and comprehensive reviews and evaluations of existing State excavation damage prevention programs and recommend changes and improvements, where warranted, such as full participation, administrative enforcement of the program, pre-marking requirements, and training requirements for all personnel involved in excavation activity.

ACCURACY OF INFORMATION REGARDING BURIED FACILITIES

Underground Detection Technologies

Both facility owners and excavators have genuine interest in identifying the location of underground facilities. But with current locating equipment technologies and mapping records, there remains a variety of errors that can potentially affect the ability to positively identify the position of underground facilities. There is no one procedure or tool that can provide accurate location information for all types

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of facilities in all types of situations. Location work is a combination of operator experience and the correct use of technology.

A variety of remote sensing technologies can be used for detecting underground facilities. Different types of locating equipment and techniques are needed depending on structural composition of the buried materials, soil composition, and surface access [55]. A brief description of the types and attributes of locator tools is shown in Table 12.3. In addition to equipment choice, there are situational variables that affect detection accuracy. The more conductive the soil, the more shallow the conductor will appear. Sandy, loose soil with a high mineral content will give sensitive readings; pipe locations under these conditions may be deeper than the locator equipment readings indicate. Moisture content or water table levels can also affect depth readings.

For equipment types that determine location by sensing an electronic signal that has been introduced into the underground system, strength of the locating signal depends on where the signal was introduced into the system, the proximity of structural uprights connected to the underground system, and nearby surface obstructions that dissipate the signal. Selection of radio signal frequency can also affect signal clarity. Equipment readings cannot be taken as absolute values; they depend on situational effects associated with locator equipment calibration, field conditions, and the operators familiarity with the particular operating characteristics. Many water and sewer lines are made of plastic or concrete pipe, gas systems commonly use plastic pipe, and fiber optic cable is often used in telecommunication lines. These systems are difficult to detect with common locator tools because they do not contain metal. A metal tracer wire can be buried with the pipe to facilitate future locating work. Typically, pipe is laid in the trench and covered by a shallow layer of fill dirt. The tracer wire is then placed over the pipe and trench filling is completed. Detectable warning tape—aluminum foil covered with color-coded polyester—can be buried with nonmetallic underground facilities to permanently mark the lines. Varieties of tracer wire and detectable warning tape are designed to be sturdy enough to be plowed into the trench during backfill operations.

The Safety Board recognizes industry efforts to inform locators about issues relevant to locator technology. Underground Focus magazine sponsors an annual utility locating technology seminar. This training event, currently in its 6 th year, provides information on utility locating techniques, equipment, and new technology. Participants include locators, equipment manufacturers, engineers, trade association representatives, and academic interests. Topics related to locator equipment are also regularly addressed at conferences such as the annual OCSI symposium and the Underground Safety Association forum [56].

VERTICAL/DEPTH LOCATION

The only certain method of determining facility depth is to expose the pipe, conduit, or cable through hand digging or through vacuum excavation. Southwestern

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Types of locator equipment.

Equipment type	Functional description	Attributes
Radio frequency (RF) detection techniques	Conventional underground line detection method. Requires a transmitter and a receiver. Conductive tracing attaches the transmitter directly to the line or tracer wire. Inductive tracing does not require direct line connection.	Oldest, most widely used technology. Inductive signal detection is quicker, but conductive signal reading is more accurate.
Electromagnetic techniques	Records signal differentials of magnetic fields. Similar to radio frequency technology.	Useful for detecting metal objects or structures that exhibit strong magnetic fields at the ground surface. This type of detector is affected by obstructions between the transmit signal and the locating equipment.
Magnetic methods	Useful for detecting iron and steel facilities.	Magnetic flux methods are easy to use and inexpensive, but they are subject to interference from metal surface structures.
Vacuum extraction	Small test holes are dug from the surface by vacuuming out the soil. The activity, usually referred to as "potholing," follows more preliminary locating work to identify the general facility location. The pothole then confirms the location and verifies a depth for that specific site.	Requires preliminary records search to approximate location for potholing and special vacuum equipment. Process can be expensive and labor intensive.
Ground penetrating radar	Radar wave reflections from underground surfaces of different dielectric constants are used to identify subsurface structures.	This method is relatively expensive compared to other locator methods and does not work well in clay or saltwater.
Terrain conductivity	Detects current measures that differ from average ground surface conductivity.	This method can be useful in areas of high conductivity, such as marine clay soils, particularly for locating underground storage tanks.
Global positioning system (GPS)	Uses triangulated satellite telemetry to identify latitude/longitude location of ground unit.	While not a detection technology, GPS coordinates are frequently used to define geographic location.

Adapted from: Anspach, J.H. 1994. Locating and Evaluating the Conditions of Underground Utilities. In: RETROFIT '94. Washington, DC: National Science Foundation. Sponsored by: Stanford University and the National Science Foundation.

FIGURE 12.4 Types of locater equipment.

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Bell's use of vacuum excavation to expose and document exact facility locations is credited with decreasing cable damages by 50 percent in Texas during 1996 [57]. This method positively identifies both the horizontal and vertical location of the pipe at a specific site. But certainty about the line's position is inversely related to its distance from the test hole. Depth depends on how the line was installed and on the changes in surface grade caused by erosion or construction since installation.

For selected models of locating equipment, manufacturers claim that the units can accurately determine depth [58]. Accurate depth measurements are a highly desirable attribute of locating equipment. Based on equipment manufacturers' claims, States have begun to consider adding requirements for depth location information to their damage prevention legislation. Wyoming's Underground Facilities Notification Act of 1996 requires construction project owners to furnish information on the nature, location, and elevation of underground facilities.59 Minnesota is considering a similar requirement.

Remote locating devices that measure depth are susceptible to calibration problems, antenna misalignment, and electronic fields that are combined from more than one surface conductor [60]. The capability for accurate depth measurement may exist under ideal situations, but given field conditions, depth measures may lack a high rate of reliability. Participants in the 1994 damage prevention workshop concluded that remote sensing methods should not be used for determining facility depth location. More recently, at the 1997 One-Call Systems and damage prevention symposium, a session on depth perception concluded that remote locator equipment was available that could provide elevation readings but not with a degree of accuracy that warrants placing the liability with the locating service [61].

The capability of locator equipment needs to be incorporated into damage prevention practices. The Safety Board concludes that more research and testing is needed to determine the accuracy of depth detection by remote locating equipment. Therefore, the Safety Board believes that RSPA should sponsor independent testing of locator equipment performance under a variety of field conditions. Further, the Board believes that as a result of the testing, RSPA should develop uniform certification criteria of locator equipment. Finally, once locator equipment performance has been evaluated and defined by certification criteria, RSPA should review State requirements for location accuracy and hand-dig tolerance zones to determine that they can be accomplished with commercially available technology.

DIRECTIONAL BORING/TRENCHLESS TECHNOLOGY

Excavation work is frequently for the purpose of installing additional facilities. General practices require digging an open trench from the surface down to the installation depth. However, trenchless technology offers a different method for installing underground facilities. Directional boring "snakes" a new line that fol-

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lows a drill bit horizontally through the subsurface. This method is particularly advantageous for traversing below waterways, ecologically sensitive wet lands, or major traffic arteries. But there are practical limits to the depth that lines are installed. Eventually, additional depth becomes infeasible because of the cost of the extended line runs, geologic changes at lower stratum, or practical concerns for future maintenance. New lines must then go through the areas that have had line laid by directional boring.

Differences in soil density, rock formations, and variable torque on the drilling head often result in a directional line that does not run along a straight route. Drilling heads can be deflected by hard rock or unknown underground objects. The operational accuracy of directional boring depends on the accuracy of sensors located on the drill bit and the drilling unit's resolution and correlation to a common base map. Though they do not involve sensors, similar problems can be found with the use of pneumatic drills and mechanical augers.

Directional boring is not always sensitive to line hits; it is possible for a boring equipment operator to hit a facility without being aware of the hit. The drill bits, designed to go through rock, experience little change in resistance when going through plastic pipe or cable. This sets up a situation for hitting a gas line without knowing it; migrating gas can then collect, creating conditions for an explosion. The Safety Board recently investigated an accident involving directional boring in Indianapolis, Indiana [62]. The explosion resulted in one fatality, one injury, and extensive damage to a residential subdivision.

Over the past year, the trade literature has documented several accidents, not investigated by the Safety Board, that resulted from horizontal directional boring. For example:

- In Seattle, directional boring caused a gas explosion that destroyed a home
- A major traffic artery in northern New York State was closed for several days to determine if a water main break resulting from directional boring had seriously weakened the roadbed
- Two people were hospitalized in Overland Park, Kansas, when a gas explosion, caused by directional boring, destroyed four homes [63]

Equipment manufacturers have tried to address the problem of recording the position of lines installed by directional boring. Sensors, generally magnetic guidance-type sensors attached to the drill bit, record location information for mapping the line. The relative position of the drill bit is plotted on a real-time display at the drilling operator's control position [64]. Stored as an electronic data file, this information can be archived in facility data records. Conceptually, this accounts for "recording the course of a new line." Associated issues, however, can affect the accuracy of information gathered in this manner. First, accuracy depends on sensor calibration. Operators must know how to check for and correct calibration error. Second, the drill's sensor may know where it is in relation to some global positioning system (GPS) coordinates, but it may not know its location in relation to ground surface. Depth of line, an important fact, is dependent

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on accurately orienting the drilling activity on a topographic survey map. The accuracy of the topographic map is, in turn, affected by erosion and grade changes over time.

The Safety Board concludes that facility maps should have a standard depiction for underground facilities that were installed using directional boring techniques. The Safety Board believes that the APWA should work in conjunction with the American Society of Civil Engineers (ASCE) to develop standards for map depiction of underground facilities that were installed using directional boring techniques.

MAPPING

Maps are important to many aspects of excavation damage prevention. Rather than using a standard, common mapping system, current damage prevention programs use many different maps. An excavator usually uses a city road map to identify to the one-call center the intended area of construction activity. The one-call center refers to its coverage map (grid system coded with database information) to identify which facility owners should be notified to mark their underground facilities. Locators use a combination of utility maps to direct their field work.

Engineers and project designers are forced to use a variety of data sources from both public and private organizations to determine the structure and location of the under-ground facility network. Land use and zoning maps, tax assessor maps, easement descriptions, highway and transportation network maps, quadrangle and topographic maps of the U.S. Geologic Survey, construction permit drawings, construction plans, and aerial photographs are also used to help define the location. As the following example illustrates, map quality can vary. Excavation to install telephone cable on the University of New Haven campus in Connecticut in August 1996 hit a gas main, but the gas did not ignite. The gas crew searched for 33 minutes to find the correct shutoff valve. The director of facilities for the university said the gas line was not marked on maps of the campus [65].

Facility records maintained by the utility owners or pipeline operators are the most widely used sources of information about the underground infrastructure. As a result of the Pipeline Safety Act of 1992, OPS requires operators to identify facilities in environmentally sensitive areas and in densely populated areas, but there is no requirement for system operators to maintain a comprehensive system map of their underground facilities, though most do maintain this information to facilitate their business operations. Different utility services use different types of maps; they vary in scale, accuracy, resolution, standard notation, and data format. System records developed prior to the widespread use of computer technology most likely exist as architectural and engineering diagrams. For some systems, these diagrams have been electronically imaged so that they are easier to refer-

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ence, update, and store. Digitized versions of early maps do not always reflect the uncertainty of information that may have been inherent on the hand-drafted version. Structural references and landmarks that define the relative locations of underground facilities also change over time and may not be reflected on maps.

Many system maps lack documentation of abandoned facilities. Abandoned facilities result when the use of segments of the underground system are discontinued, or when replaced lines run in new locations, or when entire systems are upgraded. Without accurate records of abandoned facilities, excavators run the risk of mistaking the abandoned line for an active one, thereby increasing the likelihood of hitting the active line. Several States have recognized the need to require facility operators to map abandoned lines; for example, Arizona requires that any line abandoned after December 1988 be mapped.

In addition to documenting the location of a facility, utility map records may also contain information on the age of the facility, type and dimensions of the material, history of leakage and maintenance, status of cathodic protection, soil content, and activity related to pending construction. However, the quality of this information varies widely. Participants at the 1994 damage prevention workshop recommended that when excavation revealed errors in mapping, operators should be required to update system maps.

Recent utility records often exist as geographical information systems in a variety of computerized software packages and electronic data storage formats. The Mapping Requirements and Standards task group of the AGA's Distribution Engineering Committee surveyed member companies in 1995 about mapping requirements and practices. Of the 27 companies that responded, 12 used computerbased mapping systems, 12 others were planning to automate their mapping systems, and 3 reported that they had no plan to automate mapping records [66].

Many automated mapping programs are not compatible, and it is difficult to merge system records developed over the years by different departments and companies. Additionally, computerized diagrams may be associated with large databases that contain entry errors that are difficult to identify. Inconsistencies between data dictionaries—similar information labeled differently in different databases—require considerable effort to correct once identified. More importantly, these differences may lead to an unknown error if they are not resolved. A good quality printed image of an electronic map can disguise the poor level of information used to generate the image.

One-call systems are beginning to use GPS receivers and mapping programs [67]. Arizona Blue Stake One-Call and Ohio Utility Protection Service are working to develop positionally accurate, map-driven software to support their notification systems. California's USA North One Call ticket locations can be displayed as GPS coordinates [68]. Excavators, locators, and utility operators can use GPS information to identify field locations (longitude and latitude coordinates), and they can use this information to navigate to the sites. With the added capability of differential GPS, objects can be located to an accuracy of better than 1 meter (1.1 yards). This degree of accuracy makes differential GPS appropriate

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for many aspects of mapping underground facilities. The Tennessee One-Call System is considering the feasibility of installing differential GPS antennas across the State to provide location accuracy.

Most commercial maps are based on topographically integrated geographic encoding and referencing (TIGER) files from the U.S. Census Bureau. These files often contain positional inaccuracies that can be problematic when integrated with GPS latitude and longitude coordinates. For example, many, if not most, existing underground systems are not documented by GPS coordinates. Consequently, a facility owner working on a line may want to update the positional record of that line to include the coordinates. Using a GPS receiver, the facility owner acquires the line's position and then references a TIGER-based map for that area to verify aboveground landmarks. The map can indicate that those coordinates are on the south side of the highway, yet the locator might actually be standing above the underground facility on the north side of the highway.

In 1994, the Federal Geographic Data Committee recommended a plan for the Nation's spatial data infrastructure, and Congress mandated governmental response to the plan [69]. The OPS subsequently formed a joint government/industry team to start a national pipeline mapping system. The team's 1996 report, "Strategies for Creating a National Pipeline Mapping System," made several recommendations: (1) develop, promote, and aggressively communicate pipeline data standards that are consistent with the standards of the Federal Geographic Data Committee; (2) formalize a partnership with industry, and Federal and State agencies; (3) develop a partnership with One-Call Systems International to reach a better understanding of one-call system data needs and gather support for using geographically referenced data; and (4) create a distributed mapping system with centralized quality control and decentralized access capabilities.

There are many different facility mapping systems in use by one-call systems and facility owners. Those with GPS positional accuracy lack information on landmarks and developed structures, and maps that accurately reflect current structural improvements often lack positional accuracy. The Safety Board concludes that underground facility mapping must consider the amount of detail and the accuracy of information necessary for effective use. The Safety Board recognizes RSPA's effort in creating strategies for a national pipeline mapping system and for its current Mapping Implementation Quality Action Team. The Board believes RSPA should develop mapping standards for a common mapping system, with a goal to actively promote its widespread use.

SUBSURFACE UTILITY ENGINEERING

Subsurface utility engineering (SUE) is a process for identifying, verifying, and documenting underground facilities. Depending on the information available and the technologies employed to verify facility locations, a level of the quality of information can be associated with underground facilities. These levels,

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shown in Table 12.4, indicate the degree of uncertainty associated with the information; level A is the most reliable and level D the least reliable. This categorization is a direct result of the source of information and the technologies used to verify the information.

A comprehensive map and automated computer diagram of a construction site is developed as a SUE product; it depicts coregistered information for all utilities in that area. The SUE process identifies all utilities during a single coordinated effort. In this way, information known about one facility can beneficially affect the mapping of other utilities, and unknown facilities are more likely to be documented. By signing the SUE product, a professional engineer warrants the maps against errors and omissions and assumes liability for the accuracy of the information.

The Federal Highway Administration (FHWA) considers SUE an integral part of preliminary engineering work on highway projects receiving Federal aid. It has the potential to reduce facility conflicts, relocation costs, construction delays, and redesign work. In 1984, the State of Virginia began a SUE program, called the Utility Designation and Locating Program, and determined that there were substantial cost savings. A highway project in the city of Richmond used SUE work costing $93,553 to avoid an estimated $731,425 worth of expenses to move utilities had the highway projects not been designed to avoid conflict with underground facilities. Virginia's estimate of cost savings, just in terms of avoiding utility relocations, was $4 saved for each dollar spent.

Additionally, Virginia credits the process with reducing design time by 20 percent [70]. The utility coordinator for Maryland's State Highway Administration estimates a savings of $18 for each dollar spent. Florida DOT found that it saved $3 in contract construction delay claims for each dollar spent on SUE. Variations in these estimates reflect different cost assumptions, geographic conditions, and system configurations. Twenty-six highway agencies have used SUE at some level on some projects; FHWA estimates a nationwide savings of $100 million a year as a result of SUE [71, 72].

Compiling comprehensive information on underground facilities can be expensive and labor intensive. Small contractors generally do not have the resources or expertise available to accomplish SUE on a regular basis; consequently, SUE is generally used on large construction projects such as those typical of highway development.

Architects, engineers, and contractors should have ready access to information on the location of underground facilities to plan construction activities. The advantage of this information was recognized at the 1994 damage prevention workshop. The Safety Board concludes that providing construction planners with information on the location of underground facilities, referred to as "planning locates," can reduce conflicts between construction activities and existing underground facilities. The Safety Board believes that the APWA should encourage one-call notification centers to work with their members to provide facility location information for the purpose of construction planning.

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Subsurface utility engineering (SUE) levels of information.

Quality level of the information	Description
Level D	Information is collected from **existing utility records** without field activities to verify the information. The accuracy or comprehensiveness of the information cannot be guaranteed; consequently, this least certain set of data is the lowest quality level.
Level C	**Adds aboveground survey data** (such as manholes, valve boxes, posts, and meters) to existing utility records. The Federal Highway Administration Office of Engineering estimates that 15–30 percent of level C facility information pertinent to highway construction is omitted or plotted with an error rate of more than 2 feet.[a]
Level B	**Confirmed existence and horizontal position of facilities are mapped** using surface geophysical techniques. The two-dimensional, plan-view map is useful in the construction planning phase when slight changes to avoid conflicts can produce substantial cost savings by eliminating the relocation of utilities.
Level A	Vacuum excavation is used to **positively verify both the horizontal and vertical depth location** of facilities.

[a] Scott, Paul. 1995. "Subsurface Utility Engineering: An Alternative to Excavation Damage." In: Proceedings, Excavation Damage Prevention Workshop; 1994 September 8-9; Washington, DC. Report of Proceedings NTSB/RP-95/01. Washington, DC: National Transportation Safety Board: 186-189.

Source: Stutzman, H.G.; Anspach, J.H. 1993. "Site Investigation and Detection." In: Research Needs in Automated Excavation and Material Handling: Proceedings, National Science Foundation Symposium; 1993 April. Washington, DC: National Science Foundation.

FIGURE 12.5 Subsurface utility engineering (SUE) levels of information.

The Standards Committee of the ASCE is developing standards for depicting underground facilities on construction drawings. The Board thus believes that the APWA and the ASCE should address the accuracy of information that depicts subsurface facility location on construction drawings. Further, the Safety Board believes that the Associated General Contractors of America should promote the use of subsurface utility engineering practices among its members to minimize conflicts between construction activities and underground systems.

SYSTEM PERFORMANCE MEASURES

Few performance-based measures are available and useful for assessing excavation damage prevention programs. Those measures that are maintained are specific to selected States or are maintained by individual companies for a specific underground system. Data concerning underground damage for all types of systems are needed:

1. to determine if changes to State damage prevention programs are effective in decreasing underground facility damage
2. to assess the benefit of different practices followed by one-call notification centers

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3. to identify the risks of different field practices used by facility operators, locators, and excavators
4. to allow facility operators to evaluate their company's excavation damage prevention programs
5. to assess the needs and benefits of training; and (6) to perform risk assessment for the purposes of business, insurance, and public policy decisions

RISK EXPOSURE

A critical component of excavation damage data is the total number of excavations that present a chance for damage. These data, however, are not available. The number of excavations presented in this report are industry estimates; they did not result from a national data collection system. To quantify the number of accidents in relation to how many could have occurred, it is necessary to determine some frequency of exposure. In the context of excavation damage, exposure can be measured by the number of excavations. This measure can be approximated by the number of locate tickets issued by one-call centers, although that number will capture only those excavations that were reported to one-call centers.

One-call centers offer the best opportunity for the industry as a whole to determine the rate of excavation damage. The OCSI Delegate Committee is developing a process to standardize and collect one-call center information from its members. To be useful, the information will need to be qualified by reporting criteria. Categories will need to be clearly defined: what is an excavation activity, what constitutes a facility hit, how is the level of damage categorized, what caused the damage?

Many facility operators, particularly companies that transport gas and hazardous liquids, investigate and record "line hits" in terms of damages per thousand locate requests. But because of proprietary interests, these numbers are rarely compiled across companies. The Gas Research Institute's (GRI) 1995 study made an effort to determine risk exposure for the gas industry [73]. The study surveyed 65 local distribution companies and 35 transmission companies regarding line hits. Less than half (41percent) of the companies responded, and several major gas-producing States were poorly represented (only one respondent from Texas and one from Oklahoma). The GRI estimate was determined by extrapolation and may be subject to a large degree of error because the data sample was not representative. Based on survey responses, however, GRI calculated an approximate magnitude of risk. For those companies that responded, a total of 25,123 hits to gas lines were recorded in 1993; from that, the GRI estimated total U.S. pipeline hits in 1993 to be 104,128. For a rate of exposure, this number can be compared to pipeline miles: for 1993, Gas Facts reported 1,778,600 miles (2 861 767.4 kilometers) of gas transmission, main, and service line, which calculates to a risk exposure rate of 58 hits per 1,000 line miles (1609 kilometers) [74].

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Because the risk of excavation damage is associated with digging activity rather than system size, "hits per digs" is a useful measure of risk exposure. For the same year that GRI conducted its survey, one-call systems collectively received more than an estimated 20 million calls from excavators. (These calls generated 300 million worksite notifications for participating members to mark many different types of underground systems.) Using GRI's estimate of hits, the risk exposure rate for 1993 was 5 hits per 1,000 notifications to dig [75]. A comprehensive measure of hits per digs tracked over time can be a useful indicator of how well excavation damage prevention programs are performing. Because the measure is expressed as a rate rather than simply a number of hits, it can be used to compare years in which there were different levels of construction activity. The measure can also be used to compare geographic locations or utility systems of different size. Industry is beginning to use such measures of performance; for example, measures of hits per locates have been incorporated into contractual agreements between utilities and their locator services [76].

The Safety Board is encouraged that attempts are being made to calculate risk exposure data. Without this information, evaluations on the effectiveness of State damage prevention programs cannot be adequately performed. The Safety Board is concerned, however, that these isolated attempts to calculate exposure data are neither standardized nor centrally reported. A "utility" in one State may be defined differently for another State, resulting in inconsistent measures of damage.

If all digging activity were recorded through one-call systems, notification ticket volume would be a useful measure of risk exposure. The Safety Board recognizes that not all excavators currently use one-call notifications systems and that there are 84 separate one-call systems operating in the United States collecting different information in different formats. The Safety Board concludes that the one-call notification centers may be the most appropriate organizations to collect risk exposure data on frequency of digging and data on accidents. To standardize how and what information should be collected, the Safety Board believes that the APWA, in conjunction with RSPA, should develop a plan for collecting excavation damage exposure data and then work with the one-call systems to implement the plan to ensure that excavation damage exposure data are being consistently collected. The universal damage report form developed by Alberta One-Call could be considered by the OCSI. Finally, the Safety Board believes that the APWA and RSPA should use excavation damage exposure data in the periodic assessments of the effectiveness of State excavation damage prevention programs described in other safety recommendations in this report.

ACCIDENT REPORTING REQUIREMENTS OF RSPA

The requirements and criteria for reporting natural gas and hazardous liquid pipeline accidents are found in 49 CFR Part 191.3 and Part 195.50, respectively.

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A natural gas incident report is required for:

1. an event that involves release of gas causing a death, or personal injury necessitating in-patient hospitalization, or property damage or loss of $50,000 [77]
2. an event that results in an emergency shutdown
3. an event that is significant in the judgment of the operator.

For hazardous liquids, an accident report is required for any of the following conditions:

1. Explosion or fire not intentionally set by the operator
2. Loss of 50 or more barrels of liquid product
3. Escape to the atmosphere of more than 5 barrels a day of volatile liquids
4. Death of any person
5. Bodily harm
6. Estimated property damage exceeding $50,000.

RSPA receives accident reports on only a small portion of the underground infrastructure, not as a result of failure to report on the part of industry, but because RSPA's oversight responsibilities are limited to only a portion of the gas and hazardous liquids systems, and of that subset, accident reports are required only when reporting thresholds are exceeded. Nonetheless, RSPA's database is important because there are few sources for national accident measures and because RSPA's experience in collecting pipeline accident data can be useful for designing future databases on excavation damage. According to the GRI study of damage prevention, gas transmission and distribution systems accident reports by RSPA account for less than 1 percent of the occurrences of underground pipeline damage [78]. Although numerous accidents and incidents do not meet the above reporting criteria and, consequently, are not recorded by RSPA, the Safety Board is concerned that many accidents that should be reported are not being reported because the cost of damage is underestimated. For example, a recent university study determined that a gas line rupture, originally reported to cost $15,000, cost substantially more [79]. Survey responses from businesses, homeowners, and emergency response units determined that the cost of the accident, not including the cost of lost gas or legal fees associated with ongoing litigation, was over $300,000. Because of the $50,000 reporting threshold, this accident, based on the original damage estimate, was not required to be reported to RSPA.

Although a determination by the operator that an incident costs less than $50,000 alleviates the operator of the requirement to report the incident to RSPA and may be a factor in the under-reporting of accidents, estimating property damage can be difficult and very subjective. The incident reports filed by operators ask for estimated property damage; however, little guidance is provided to operators on all costs that should be included to ensure accurate reporting. Dollar amounts

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are generally assumed to represent product loss, facility damage incurred by the operator and others, and the environmental cleanup cost; however, the exclusion of any one of these costs could reduce the estimated damage to below the reporting threshold. As a result, the accident would not be reported to RSPA. The Safety Board concludes that facility operators are provided little guidance for estimating property damage resulting from an accident, and subjective estimates of damage below the reporting threshold may account for some accidents not being reported to RSPA when they should have been. Therefore, the Safety Board believes that RSPA should develop and distribute to pipeline operators written guidance to improve the accuracy of information for reportable accidents, including parameters for estimating property damage resulting from an accident.

ACCIDENT CAUSES

The accident report form for hazardous liquid pipelines offers seven categories of cause [80]. For accidents reported between 1986 and 1995, three categories (corrosion, outside force damage, and other) accounted for 78 percent of the reported accidents. For 1996, RSPA data indicated that "outside force damage" was the leading cause of accidents (damage by outside force is primarily, though not exclusively, the category in which excavation damage is placed). The second leading cause for that year was "other." The Safety Board has previously expressed concern that the definition of accident cause is imprecise and that distinctions between categories of cause are vague. For example, in the data for hazardous liquid pipeline accidents, pipeline accidents resulting from similar events (as described by text explanations) are categorized differently. Accidents described as "lightning strike," "vandalism," "drilled into pipe," and "bullet hole" appear in both the "outside force damage" and "other" categories. Because excavation damage is not separately categorized, Safety Board staff conducted a systematic review of the accidents reported to RSPA for the years 1991 through 1996 to determine the number of excavation-related accidents (Table 12.5). The review indicated no trend toward a long-term decrease in excavation-related accidents (Figure 12.2).

Numerous accident records in the databases for distribution, transmission, and hazardous liquids systems show $0.00 for accident costs [81]. This is particularly disturbing because in one case, a damage cost of $0.00 was reported for an accident that injured 12 persons (a distribution system accident, July 1996 in Brooklyn, New York). A review of text comments associated with the accident records indicated that most excavation damage accidents were classified in the database as "outside force damage." However, there were many additional accidents classified as "outside force damage" that were not excavation-caused and several incidents of excavation damage were mis-categorized as "other," "corrosion," "accidentally caused by operator," or "construction/operating error."

Based on this review and previous analysis of RSPA data, the Safety Board concludes that deficiencies in RSPA accident data, particularly with respect to the cause of accidents and a record of whether those involved in pipeline accidents

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Proportion of accidents that were excavation-related, 1991 through 1996.

System type and item	1991			1992			1993		
	All accidents	Excavation accidents[a]	Percentage	All accidents	Excavation accidents[a]	Percentage	All accidents	Excavation accidents[a]	Percentage
Distribution:									
Accidents	165	59	35.8	103	35	34.0	119	33	27.7
Injuries	78	29	37.2	65	20	30.8	82	27	32.9
Fatalities	14	6	42.9	7	2	28.6	16	7	50.0
Property damage (million)	$7.9	$3.1	39.0	$6.8	$1.5	21.5	$14.7	$3.7	25.1
Transmission:									
Accidents	72	28	38.9	75	11	14.7	97	16	16.5
Injuries	12	2	16.7	15	3	20.0	18	2	11.1
Fatalities	0	0	0	3	2	66.7	1	0	0
Property damage (million)	$12.0	$1.9	15.8	$24.7	$1.0	4.0	$23.0	$0.7	3.2
Hazardous liquids:									
Accidents	220	43	19.5	223	42	18.8	229	51	22.3
Injuries	9	1	11.1	38	8	21.1	10	5	50.0
Fatalities	0	0	0	5	0	0	0	0	0
Property damage (million)	$25.5	$6.5	25.4	$64.4	$29.1	45.3	$29.2	$13.4	45.8
Total:									
Accidents	457	130	28.4	401	88	21.9	445	100	22.5
Injuries	99	32	32.3	118	31	26.3	110	34	30.9
Fatalities	14	6	42.9	15	4	26.7	17	7	41.2
Property damage (million)	$45.3	$11.4	25.2	$95.9	$31.6	32.9	$67.0	$17.8	26.6

FIGURE 12.6 Proportion of accidents that were excavation-related, 1991 through 1996.

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Proportion of accidents that were excavation-related, 1991 through 1996.

	1994			1995			1996		
	All accidents	Excavation accidents[a]	Percentage	All accidents	Excavation accidents[a]	Percentage	All accidents	Excavation accidents[a]	Percentage
(continued)									
Distribution:									
Accidents	125	37	29.6	103	38	36.9	120	36	30.0
Injuries	86	25	29.1	47	17	36.2	69	31	44.9
Fatalities	18	4	22.2	12	1	8.3	22	4	18.2
Property damage (million)	$50.2	$4.4	8.7	$12.6	$1.7	13.5	$12.2	$4.6	$37.8
Transmission:									
Accidents	69	7	10.1	68	10	14.7	73	19	26.0
Injuries	12	8	66.7	12	0	0	4	0	0
Fatalities	0	0	0	2	0	0	1	0	0
Property damage (million)	$43.3	$25.3	58.4	$11.1	$1.2	11.2	$12.5	$2.2	17.8
Hazardous liquids:									
Accidents	206	24	11.7	214	34	15.9	211	42	19.9
Injuries	930	0	0	13	0	0	13	7	53.8
Fatalities	1	1	100.0	3	0	0	5	3	60.0
Property damage (million)	$49.8	$2.7	5.5	$38.3	$8.7	22.8	$41.6	$6.2	14.9
Total:									
Accidents	400	68	17.0	385	82	21.3	404	97	24.0
Injuries	1,028	33	3.2	72	17	23.6	86	38	44.2
Fatalities	19	5	26.3	17	1	5.9	28	7	25.0
Property damage (million)	$143.3	$32.4	22.6	$62.2	$11.7	18.8	$66.3	$13.0	19.6

[a] Using data maintained by the Office of Pipeline Safety, Research and Special Programs Administration, the Safety Board charactertized the accidents/incidents that were determined to be excavation-related based on incident text descriptions, then calculated the proportion of injuries, fatalities, and property damage.

Source: Office of Pipeline Safety, Research and Special Programs Administration.

FIGURE 12.6 *(continued)* Proportion of accidents that were excavation-related, 1991 through 1996.

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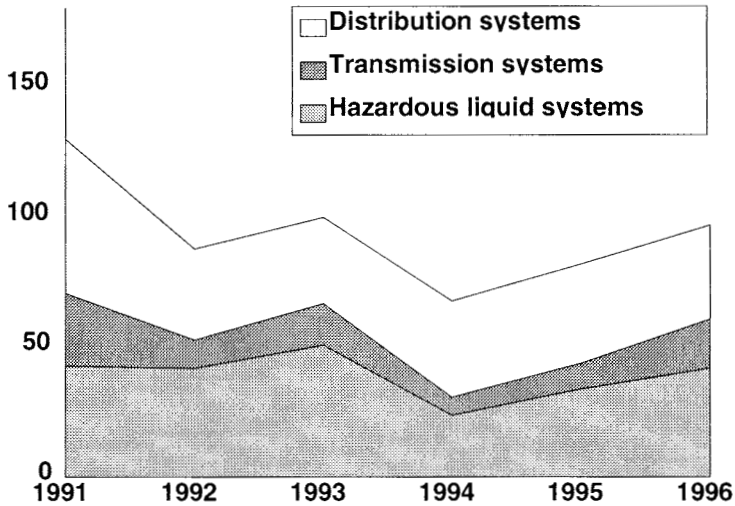

FIGURE 12.7 Number of excavation-related accidents for distribution, transmission, and hazardous liquid systems, 1991-1996.

participated in excavation damage prevention programs, precludes effective analyses of accident trends and evaluations of operator performance. Although RSPA and the industry consider excavation damage to be one of the leading causes of pipeline accidents, excavation damage is not specifically indicated on RSPA's accident form as a separate data element. A more useful analysis of accident data could also be performed if information were available on the primary, secondary, and contributing causes. The Safety Board has found through years of accident investigations that accidents are rarely the result of one event, but rather the consequence of a sequence or combination of events. Categories based on purpose of the excavation (building construction, road grading, utility maintenance); type of equipment involved (backhoe, grader, road vehicle); excavator (facility owner employee, contract employee, landowner, general public); and locator (facility owner or contract support) could provide meaningful information with which analyses of accident trends and evaluations of operator performance could be conducted.

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The Safety Board has addressed deficiencies in RSPA's accident data on several previous occasions [82]. Most recently, in a 1996 special investigation report, the Safety Board evaluated RSPA's collection and analysis of accident data for petroleum product pipelines [83]. In that report, the Board concluded that RSPA's failure to fully implement the Safety Board's original 1978 safety recommendations to evaluate and analyze its accident data reporting needs has hampered RSPA's oversight of pipeline safety. Consequently, the Safety Board recommended that RSPA

> *Develop within 1 year and implement within 2 years a comprehensive plan for the collection and use of gas and hazardous liquid pipeline accident data that details the type and extent of data to be collected, to provide the Research and Special Programs Administration with the capability to perform methodologically sound accident trend analyses and evaluations of pipeline operator performance using normalized accident data. (P-96-1)*

RSPA indicated that it agreed with the Board's recommendation and was working with the pipeline industry to determine the value of industry's data to RSPA [84]. Industry and RSPA have conducted workshops to review data issues and, as recommended by the Safety Board, RSPA has obtained database information from the Federal Energy Regulatory Commission for analysis. The Safety Board believes that given the large percentage of accidents that are caused by excavation damage and the emphasis in recent years by industry to address and respond to these types of accidents, RSPA should, as part of its comprehensive plan for the collection and use of gas and hazardous liquid data, revise the cause categories on its accident report forms to eliminate overlapping and confusing categories and to clearly list excavation damage as one of the data elements, and consider developing categories that address the purpose of the excavation.

CONCLUSIONS

1. Full participation in excavation damage prevention programs by all excavators and underground facility owners is essential to achieve optimum effectiveness of these programs.
2. Many essential elements and activities of a one-call notification center have been identified but have not been uniformly implemented.
3. Administrative enforcement has proven effective in some State excavation damage prevention programs.
4. Pre-marking an intended excavation site to specifically indicate the area where underground facilities need to be identified is a practice that helps prevent excavation damage.

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5. Employee qualification and training is an integral component of an effective excavation damage prevention program, and industry has recognized the need for employee training but has not implemented training uniformly.
6. At a minimum, excavators should formulate an emergency response plan appropriate for the specific construction site and ensure that employees working at that site know the correct action to take if a buried facility is damaged.
7. Although considerable progress has been made to improve State excavation damage prevention programs, additional efforts are needed to uniformly develop and implement programs that are most effective.
8. More research and testing is needed to determine the accuracy of depth detection by remote locating equipment.
9. Facility maps should have a standard depiction for underground facilities that were installed using directional boring techniques.
10. Underground facility mapping must consider the amount of detail and the accuracy of information necessary for effective use.
11. Providing construction planners with information on the location of underground facilities, referred to as "planning locates," can reduce conflicts between construction activities and existing underground facilities.
12. One-call notification centers may be the most appropriate organizations to collect risk exposure data on frequency of digging and data on accidents.
13. Facility operators are provided little guidance for estimating property damage resulting from an accident, and subjective estimates of damage below the reporting threshold may account for some accidents not being reported to the Research and Special Programs Administration when they should have been.
14. Deficiencies in the Research and Special Programs Administration's accident data, particularly with respect to the cause of accidents and a record of whether those involved in pipeline accidents participated in excavation damage prevention programs, precludes effective analyses of accident trends and evaluations of operator performance.

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RECOMMENDATIONS

As a result of this safety study, the National Transportation Safety Board made the following recommendations:

To the Research and Special Programs Administration

Conduct at regular intervals joint government and industry workshops on excavation damage prevention that highlight specific safety issues, such as full participation, enforcement, good marking practices, the importance of mapping, and emergency response planning. (P-97-14)

Initiate and periodically conduct, in conjunction with the American Public Works Association, detailed and comprehensive reviews and evaluations of existing State excavation damage prevention programs and recommend changes and improvements, where warranted, such as full participation, administrative enforcement of the program, pre-marking requirements, and training requirements for all personnel involved in excavation activity. (P-97-15)

Sponsor independent testing of locator equipment performance under a variety of field conditions. (P-97-16)

As a result of the testing outlined in Safety Recommendation P-97-16, develop uniform certification criteria of locator equipment. (P-97-17)

Once locator equipment performance has been evaluated and defined by certification criteria as outlined in Safety Recommendation P-97-17, review State requirements for location accuracy and hand-dig tolerance zones to determine that they can be accomplished with commercially available technology. (P-97-18)

Develop mapping standards for a common mapping system, with a goal to actively promote its widespread use. (P-97-19)

Develop and distribute to pipeline operators written guidance to improve the accuracy of information for reportable accidents, including parameters for estimating property damage resulting from an accident. (P-97-20)

As part of the comprehensive plan for the collection and use of gas and hazardous liquid data, revise the cause categories on the accident report forms to eliminate overlapping and confusing categories and to clearly list excavation damage as one of the data elements, and consider developing categories that address the purpose of the excavation. (P-97-21)

In conjunction with the American Public Works Association, develop a plan for collecting excavation damage exposure data. (P-97-22)

Work with the one-call systems to implement the plan outlined in Safety Recommendation P-97-22 to ensure that excavation damage exposure data are being consistently collected. (P-97-23)

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Use excavation damage exposure data outlined in Safety Recommendation P-97-22 in the periodic assessments of the effectiveness of State excavation damage prevention programs described in Safety Recommendation P-97-15. (P-97-24)

To the American Public Works Association

Initiate and periodically conduct, in conjunction with the Research and Special Programs Administration, detailed and comprehensive reviews and evaluations of existing State excavation damage prevention programs and recommend changes and improvements, where warranted, such as full participation, administrative enforcement of the program, pre-marking requirements, and training requirements for all personnel involved in excavation activity. (P-97-25)

In conjunction with the Research and Special Programs Administration, develop a plan for collecting excavation damage exposure data. (P-97-26)

Work with the one-call systems to implement the plan outlined in Safety Recommendation P-97-26 to ensure that excavation damage exposure data are being consistently collected. (P-97-27)

Use excavation damage exposure data outlined in Safety Recommendation P-97-26 in the periodic assessments of the effectiveness of State excavation damage prevention programs described in Safety Recommendation P-97-25. (P-97-28)

Review existing training programs and materials related to excavation damage prevention and develop guidelines and materials for distribution to one-call notification centers. (P-97-29)

Develop guidelines and materials that address initial emergency actions by excavators when buried facilities are damaged and then distribute this information to all one-call notification centers. (P-97-30)

Encourage one-call notification centers to work with their members to provide facility location information for the purpose of construction planning. (P-97-31)

Develop standards, in conjunction with the American Society of Civil Engineers, for map depiction of underground facilities that were installed using directional boring techniques. (P-97-32)

Address, in conjunction with the American Society of Civil Engineers, the accuracy of information that depicts subsurface facility locations on construction drawings. (P-97-33)

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To the Federal Highway Administration

Require State transportation departments to participate in excavation damage prevention programs and consider withholding funds to States if they do not fully participate in these programs. (P-97-34)

To the Association of American Railroads

Urge your members to fully participate in statewide excavation damage prevention programs, including one-call notification centers. (P-97-35)

To the American Short Line Railroad Association

Urge your members to fully participate in statewide excavation damage prevention programs, including one-call notification centers. (P-97-36)

To the American Society of Civil Engineers

Develop standards, in conjunction with the American Public Works Association, for map depiction of underground facilities that were installed using directional boring techniques. (P-97-37)

Address, in conjunction with the American Public Works Association, the accuracy of information that depicts subsurface facility locations on construction drawings. (P-97-38)

To the Associated General Contractors of America

Promote the use of subsurface utility engineering practices among your members to minimize conflicts between construction activities and underground systems. (P-97-39)

By the National Transportation Safety Board
James E. Hall John A. Hammerschmidt
Chairman Member
Robert T. Francis II John Goglia
Vice Chairman Member
George W. Black, Jr.
Member
Adopted: December 16, 1997

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12. NTSB accident Nos. DCA96FP004 (Gramercy, Louisiana; May 24, 1996); DCA97FP001 (Tiger Pass, Louisiana; October 23, 1996); and DCA97FP005 (Indianapolis, Indiana; July 21, 1997).
13. The accidents occurred at Allentown, Pennsylvania; Edison, New Jersey; Green River, Wyoming; St. Paul, Minnesota; Cliffwood Beach, New Jersey; and Reston, Virginia.
14. National Transportation Safety Board. 1995. Proceedings of the Excavation Damage Prevention Workshop; September 8-9, 1994; Washington, DC. Report of Proceedings NTSB/RP-95/01. Washington, DC.
15. In October 1990, the Safety Board adopted a program to identify the "Most Wanted" safety improvements. The purpose of the Board's "Most Wanted" list, which is drawn up from safety recommendations previously issued, is to bring special emphasis to the safety issues the Board deems most critical.
16. Estimates of the total infrastructure size are difficult to verify. Bell Communications Research used 20 million miles during the Safety Board's 1994 excavation damage prevention workshop.
17. Wright, P.H.; Ashford, N.J. 1989. Transportation Engineering: Planning and Design. 3d ed. New York: Wiley & Sons (p. 25). 776 p.

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18. The estimated number of excavations is based on the number of notifications received in 1996 by member organizations of One-Call Systems International.
19. American Farmland Trust. 1997. Farming on the Edge. Washington, DC.
20. In September 1988, RSPA's Technical Pipeline Safety Standards Committee unanimously supported extending Section 192.614 to cover onshore gas pipelines in Class 1 and 2 locations.
21. RSPA published the final rule, "Excavation Damage Prevention Programs for Gas and Hazardous Liquid and Carbon Dioxide Pipelines," in the Federal Register on March 20, 1995.
22. 49 CFR Parts 192.614 and 195.442.
23. Courtney, W.J.; Kalkbrenner, D.; Yie, G. 1977. Effectiveness of Programs for Prevention of Damage to Pipelines by Outside Forces. Final Report DOT/NTB/OPSO-77/12. Washington, DC: U.S. Department of Transportation, Materials Transportation Bureau, Office of Pipeline Safety Operations; contract DOT-OS-60521. 290 p. (The Office of Pipeline Safety Operations later became the Office of Pipeline Safety within the DOT's Research and Special Programs Administration.)
24. Transportation Research Board, National Research Council. 1988. Pipelines and Public Safety. Special Report 219. Washington, DC.
25. The Safety Board's 1973 review of OSHA regulations is contained in its special report entitled "Prevention of Damage to Pipelines" (NTSB/PSS-73/01).
26. National Transportation Safety Board. 1995. Texas Eastern Transmission Corporation Natural Gas Pipeline Explosion and Fire; Edison, New Jersey; March 23, 1994. Pipeline Accident Report NTSB/PAR-95/ 01. Washington, DC. 104 p.
27. The Conduit 3(4): 1, 4. August 1997. Spooner, WI: National Utility Locating Contractors Association.
28. National Transportation Safety Board. 1996. UGI Utilities, Inc., Natural Gas Distribution Pipeline Explosion and Fire; Allentown, Pennsylvania; June 9, 1994. Pipeline Accident Report NTSB/PAR-96/01, "Gas Piping Technical Committee Excavation Damage Prevention Guidelines"). 94 p.
29. U.S. Department of Transportation, Office of Pipeline Safety. 1995. Exemplary Practices and Success Stories In One-Call Systems. Washington, DC. May.
30. National Transportation Safety Board Accident Brief DCA94MP002; Green River, Wyoming; May 3, 1994.
31. Underspace Bulletin 3(9): 2. June 1997. Spooner, WI: Center for Subsurface Strategic Action (CSSA).
32. As defined by One-Call Systems International (OCSI), a subgroup of the American Public Works Association (APWA).
33. Pre-marking is discussed later in this chapter.
34. "Nationwide One-Call Directory." Pipeline & Utilities Construction. April 1996.
35. Don Evans of USA South cited 13,362,684 in the "Options in Load Management" session at the 22 d annual One Call Systems and Damage Prevention Symposium, April 20-23, 1997, New York City.
36. Kelly, Walter. 1996. Making One-Call Work for You. Constructor, November 1996: 19.
37. Correspondence dated February 10, 1997, from L.D. Shamp, representing the OCSI, to the Association of Oil Pipe Lines. The letter offered comments and suggestions regarding the provisions of the proposed one-call legislation.
38. Transportation Research Board, National Research Council. 1988. Pipelines and Public Safety. Special Report 219 (p. 133). Washington, DC.

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39. Underspace Bulletin 2(11): 2. August 1996. Spooner, WI: Center for Subsurface Strategic Action (CSSA).
40. National Transportation Safety Board. 1995. Proceedings of the Excavation Damage Prevention Workshop; September 8–9, 1994. Report of Proceedings NTSB/RP-95/01 (p. 16). Washington, DC.
41. National Transportation Safety Board Accident Brief DCA86FP004.
42. "Connecticut Data Reveals Damage Causes." Underground Focus 10(5): 17. July/August 1996.
43. "New Jersey Takes a Hard Line on Underground Damage Prevention." Underground Focus 11(3): 26-27. April 1997.
44. "News Briefs." Underground Focus 11(5): 14. July/August 1997.
45. "New Jersey Takes a Hard Line on Underground Damage Prevention." Underground Focus 11(3): 26-27. April 1997.
46. National Utility Locating Contractors Association. 1996. Locator Training Standards & Practices. Spooner, WI.
47. National Transportation Safety Board. 1986. Northeast Utilities Service Co. Explosion and Fire; Derby, Connecticut; December 6, 1995. Pipeline Accident Report NTSB/PAR-86/02. Washington, DC. As a result of the Northeast Utility Service Company's positive response to Safety Recommendation P-86-19, the recommendation was classified "Closed—Acceptable Action" on May 14, 1987.
48. National Transportation Safety Board. 1987. Chicago Heights, Illinois; March 13, 1986. Pipeline Accident Summary Report NTSB/PAR-87/01-SUM. Washington, DC. Safety Recommendation P-87-38 was classified "Closed—Acceptable Action" on September 29, 1988.
49. NTSB accident DCA93FP004. Safety Recommendation P-95-24 is currently classified "Open—Acceptable Response" pending receipt of further information from the APWA.
50. National Transportation Safety Board. 1997. San Juan Gas Company, Inc./Enron Corp. Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996. Pipeline Accident Report NTSB/PAR-97/01. Washington, DC.
51. 49 CFR Part 192.615, "Emergency plans" [for gas pipelines]; and Part 195.402, "Procedural manual for operations, maintenance, and emergencies" [for hazardous liquids].
52. NTSB accident DCA93FP008.
53. On August 1, 1995, the Safety Board classified this recommendation "Closed—Acceptable Action."
54. This recommendation is currently in an "Open—Acceptable Response" status pending further action by the APWA.
55. Anspach, J.H. 1994. Locating and Evaluating the Conditions of Underground Utilities. In: RETROFIT '94. Washington, DC: National Science Foundation. Sponsored by: Stanford University and the National Science Foundation.
56. OCSI will hold its 23 d annual symposium in March 1998, and the Underground Safety Association will hold its forum in February 1998.
57. Underspace Bulletin 3(7): 2. April 1997. Spooner, WI: Center for Subsurface Strategic Action (CSSA).
58. According to advertisements for the Sure-Lock locator by Heath Consultants, that equipment provides a continuous depth reading. Other equipment manufacturers, Fisher TW-770 and Metrotech 9800, advertise a pushbutton feature for digital display of depth.

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59. "Wyoming's Unique One-Call Legislation." Constructor, November 1996:17.
60. Anspach, J.H. 1994. Locating and Evaluating the Conditions of Underground Utilities. In: RETROFIT '94. Washington, DC: National Science Foundation. Sponsored by: Stanford University and the National Science Foundation.
61. "Depth Perception" session at the 22 d annual One-Call Systems and damage prevention symposium, April 20-23, 1997, New York City. Panel participants at the moderated session represented equipment manufacturers and underground locator services.
62. NTSB accident DCA97FP005; the accident occurred on July 21, 1997.
63. (a) Underground Focus 10(6): 16-19; 22-23. September/October 1996. (b) Underground Focus 10(7): 18-19. November/December 1996.
64. Configuration of the Mole Map System developed by McLaughlin Boring Systems.
65. Underground Focus 10(6): 17. September/October 1996.
66. Place, J.C. 1996. "Gas Utility Mapping: What's Needed, What's Used." Gas Industries, January: 21-22.
67. Vista One Call Mapping Program by Kuhagen, Inc., is compatible with California's USA North One Call System and has been accepted for use by the State fire marshal as a method for digitizing pipeline mapping.
68. "One-Calls Eye New Mapping." Underground Focus 10(2): 6. Symposium Edition 1996.
69. The Federal Office of Management and Budget (OMB), under the directive of OMB Circular A16, created the Federal Geographic Data Committee, which is chaired by the Secretary of the Interior. The 1994 Plan for the National Spatial Data Infrastructure was issued in March 1994.
70. U.S. Department of Transportation, Federal Highway Administration. 1995. Subsurface Utility Engineering Handbook. FHWA-PD-96-004 (p. I-14). Washington, DC. November.
71. According to the FHWA, Maryland, Pennsylvania, Delaware, North Carolina, and Arizona use SUE on an extensive basis.
72. U.S. Department of Transportation, Federal Highway Administration. 1995. Subsurface Utility Engineering Handbook. FHWA-PD-96-004 (p. I-29). Washington, DC. November.
73. Doctor, R.H.; Dunker, N.A.; Santee, N.M. 1995. Third-Party Damage Prevention Systems. GRI-95/ 0316. Final report, contract 5094–810–2870. Chicago, IL: Gas Research Institute. 67 p., plus appendixes.
74. Calculated as total hits (104,128)¸ miles of gas line (1,778,600) = 0.0585 hits per mile or 58.5 hits per 1,000 miles. (104,128 hits, 2 861 767.4 kilometers = 0.0364 hits per kilometer or 36.4 hits per 1000 kilometers.) Note: Different categories of gas lines were added together. Transmission lines have a substantially lower rate than other gas systems: survey respondents reported 201 hits per 36,042 line miles (57 992 kilometers), for a rate of 5.5 hits per 1,000 miles (1609 kilometers). However, GRI survey numbers account for only 10 percent of the U.S. gas transmission system. If the number of transmission system hits per 1,000 miles is separated from the U.S. total, the rate for local distribution companies increases to 71 hits per 1,000 miles.
75. Calculated as total hits (104,128)¸ excavation notifications (20,000,000) = 0.0052 per notification or 5.2 per 1,000 notifications.
76. Northern Illinois Gas incorporated a performance incentive based on hits per locates into its most recent locator service contract with Kelly Cable Corporation.

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77. Before 1984, $5,000 was the OPS property loss threshold for reporting natural gas and liquid pipeline failures. In July 1984, this threshold was increased, resulting in a sharp decline in reportable line failures after 1983.
78. Doctor, R.H.; Dunker, N.A.; Santee, N.M. 1995. Third-Party Damage Prevention Systems. GRI-95/ 0316. Final report, contract 5094-810-2870. Chicago, IL: Gas Research Institute. 67 p., plus appendixes.
79. North Carolina State University, Construction Automation & Robotics Laboratory. 1996. Assessment of the Cost of Underground Utility Damages. Raleigh, NC. 17 p., plus appendixes. The study was also the subject of the following article: Carver, C. 1996. "Real Costs of Utility Damages Researched by NCSU." Underground Focus 10(6): 28. September/October.
80. DOT Form 7000-1, Part D: (1) corrosion, (2) failed weld, (3) incorrect operation by operator personnel, (4) failed pipe, (5) outside force damage, (6) malfunction of control or relief equipment, (7) other— specify. Category 7 includes cases involving excavation damage, such as backhoe dug into line, and category 5 (outside force damage) includes vandalism and lightning strikes. Excavation damage is not separately categorized.
81. Accidents with $0.00 damage are included in the database because they meet one of the other criteria for reporting. For 1996, the three databases show 76 accidents with $0.00 damage costs.
82. See appendix for a list of Safety Board recommendations related to RSPA's accident data.
83. National Transportation Safety Board. 1996. Evaluation of Accident Data and Federal Oversight of Petroleum Product Pipelines. Pipeline Special Investigation Report NTSB/SIR-96/02. Washington, DC. 67 p. The special investigation was prompted by the ruptures of two petroleum product pipelines operated by the same company. Both ruptures occurred within a 15-month period.
84. Correspondence dated August 7, 1996, from the RSPA Administrator. On January 2, 1997, the Safety Board classified Safety Recommendation P-96-1 "Open—Acceptable Response" based on RSPA's response and pending a further progress report.

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Source: PLASTIC PIPING HANDBOOK

CHAPTER 13
BRITTLE-LIKE CRACKING IN PLASTIC PIPE FOR GAS SERVICE

Source: National Transportation Safety Board
Special Investigation Report NTCB/SIR-98/01, Washington, D.C.

INTRODUCTION

The use of plastic piping to transport natural gas has grown steadily over the years because of the material's economy, outstanding corrosion resistance, light weight, and ease of installing and joining. According to the American Gas Association (A.G.A.), the total miles of plastic piping in use in natural gas distribution systems in the United States grew from about 9,200 miles in 1965 to more than 45,800 miles in 1970 [1]. By 1982, this figure had grown to about 215,000 miles, of which more than 85 percent was polyethylene Data maintained by Office of Pipeline Safety (OPS), an office of the Research and Special Programs Administration (RSPA) within the U.S. Department of Transportation (DOT), indicate that, by the end of 1996, more than 500,000 miles of plastic piping had been installed [2]. Plastic piping as a percentage of all gas distribution piping installed each year has also grown steadily, as illustrated in Figure 13.1.

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner [3]. (see Table 13.1 for information on three recent accidents.) For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

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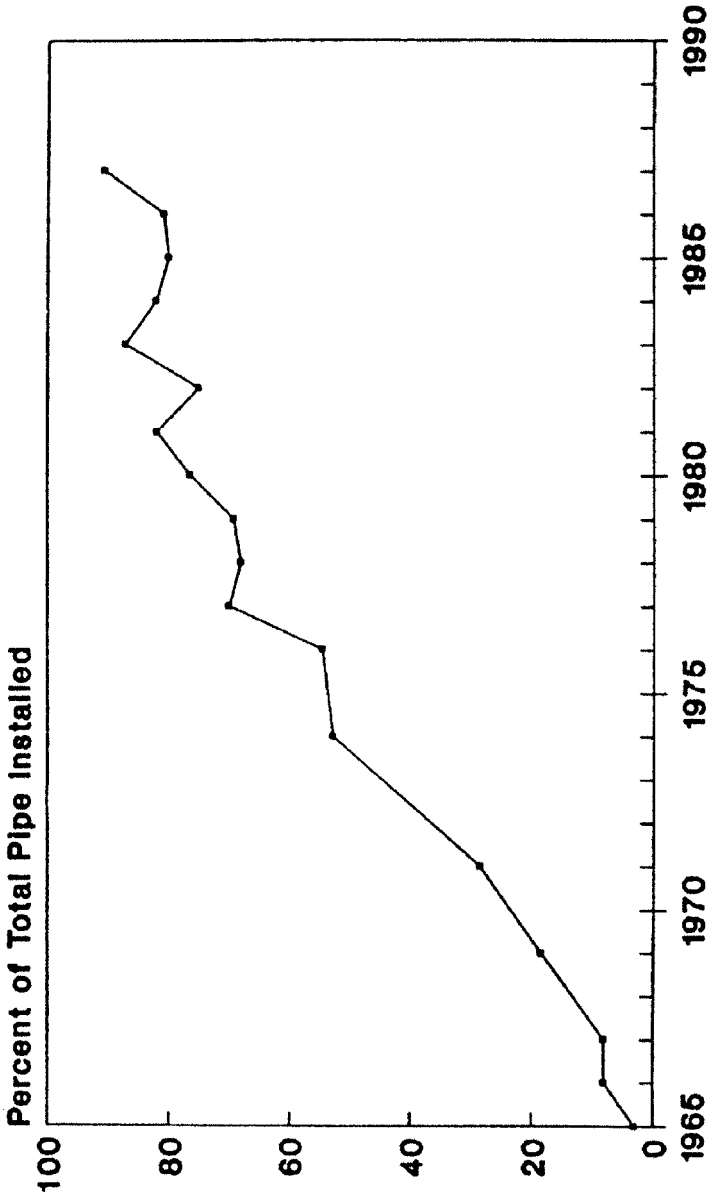

FIGURE 13.1 Plastic pipe as a percentage of all piping used in gas distribution. *(Source: Duvall, D.E., "Polyethylene Pipe for Natural Gas Distribution," presented at the Transportation Safety Institute's Pipeline Failure Investigation course, 1997. Data from Pipeline & Gas Journal surveys)*

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The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996 [4]. The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe. Stress intensification at a connection to a plastic fitting led to the formation of brittle-like cracks.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997 [5]. A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, as noted above, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by RSPA. The examination revealed that the RSPA data are insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa, San Juan, Puerto Rico, and other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:

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- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

As a result of its investigation, the Safety Board makes three safety recommendations to the Research and Special Programs Administration, one safety recommendation to the Gas Research Institute, three safety recommendations to the Plastics Pipe Institute, one safety recommendation to the Gas Piping Technology Committee, two safety recommendations to the American Society for Testing and Materials, one safety recommendation to the American Gas Association, two safety recommendations to MidAmerican Energy Corporation, two safety recommendations to Continental Industries, Inc., and one safety recommendation each to Dresser Industries, Inc., Inner-Tite Corporation, and Mueller Company.

INVESTIGATION

Accident History

On October 17, 1994, a natural gas explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that the source of the gas was a ½ inch diameter plastic service pipe that had failed in a brittle-like manner at a connection to a steel main [6].

Excavations following the accident uncovered, at a depth of about 3 feet, a 4-inch steel main. Welded to the top of the main was a steel tapping tee manufactured by Continental Industries, Inc. (Continental). Connected to the steel tee was a 1/2-inch plastic service pipe. (see Figure 13.2.) Markings on the plastic pipe indicated that it was a medium-density polyethylene material manufactured on June 11, 1970, in accordance with American Society for Testing and Materials (ASTM) standard D2513. The pipe had been marketed by Century Utility Products, Inc. (Century). The plastic pipe was found cracked at the end of the tee's internal stiffener and beyond the coupling nut.

The investigation determined that much of the top portion of the circumference of the pipe immediately outside the tee's internal stiffener displayed several brittle-like slow crack initiation and growth fracture sites. These slow crack fractures propagated on almost parallel planes slightly offset from each other through the wall of the pipe. As the slow cracks from different planes continued to grow and began to overlap one another, ductile tearing occurred between the planes. Substantial deformation was observed in part of the fracture; however, the initiating cracks were still classified as brittle-like.

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Samples recovered from the plastic service line underwent several laboratory tests under the supervision of the Safety Board. Two of these tests were meant to roughly gauge the pipe's susceptibility to brittle-like cracking. These tests were a compressed ring environmental stress crack resistance (ESCR) test in accordance with ASTM F1248 and a notch tensile test known as a PENT test that is now ASTM F1473. Lower failure times in these tests indicate greater susceptibility to brittle-like cracking under test conditions. The ESCR testing of 10 samples from the pipe yielded a mean failure time of 1.5 hours, and the PENT testing of 2 samples yielded failure times of 0.6 and 0.7 hours. Test values this low have been associated with materials having poor performance histories characterized by high leakage rates at points of stress intensification due to crack initiation and slow crack growth typical of brittle-like cracking [7, 8].

In late 1996, the Safety Board began an investigation of a November 1996 gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico. The investigation determined that the explosion resulted from ignition of propane gas that, after migrating under pressure from a failed plastic pipe at a connection to a plastic fitting, had accumulated in the basement of a commercial building. The Safety Board concluded that apparent inadequate support under the piping and the resulting differential settlement generated long-term stress intensification that led to the formation of brittle-like circumferential cracks on the pipe.

The Railroad Commission of Texas investigation of a fatal natural gas explosion and fire in Lake Dallas, Texas, in August 1997 determined that a metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

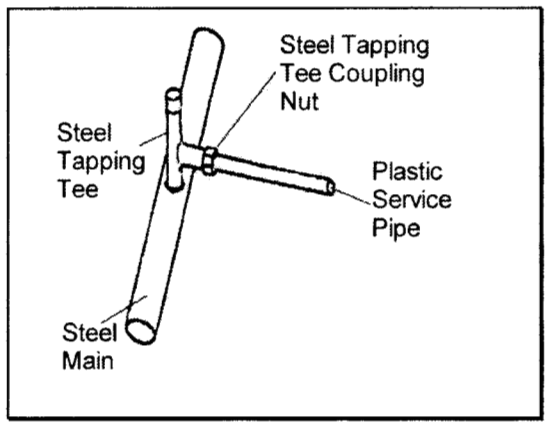

FIGURE 13.2 Typical plastic service pipe connection to steel gas main. Many connections are protected against shear and bending forces by a plastic sleeve that encloses the service pipe-to-tee connection on either side of the coupling nut.

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The Waterloo, San Juan, and Lake Dallas accidents were only three of the most recent in a series of accidents in which brittle-like cracks in plastic piping have been implicated. In Texas in 1971, natural gas migrated into a house from a brittle-like crack at the connection of a plastic service line to a plastic main [9]. The gas ignited and exploded, destroying the house and burning one person. The investigation determined that vertical loading over the connection generated long-term stress that led to the crack.

A 1973 natural gas explosion and fire in Maryland severely damaged a house, killed three occupants, and injured a fourth [10].

The Safety Board's investigation of a natural gas explosion and fire that resulted in three fatalities in North Carolina in 1975 determined that the gas had accumulated because a concrete drain pipe resting on a plastic service pipe had precipitated two cracks in the plastic pipe [11]. Available documentation suggests that these cracks were brittle-like.

A 1978 natural gas accident in Arizona destroyed one house, extensively damaged two others, partially damaged 11 other homes, and resulted in one fatality and five injuries [12]. Available documentation indicates that the gas line crack that caused the accident was brittle-like.

A 1978 accident in Nebraska involved the same brand of plastic piping as that involved in the Waterloo accident. A crack in a plastic piping fitting resulted in an explosion that injured one person, destroyed one house, and damaged three other houses [13].

The Safety Board determined that inadequate support under the plastic fitting resulted in long-term stress intensification that led to the formation of a circumferential crack in the fitting. Available documentation indicates that the crack was brittle-like.

A December 1981 natural gas explosion and fire in Arizona destroyed an apartment, damaged five other apartments in the same building, damaged nearby buildings, and injured three occupants [14].

The Safety Board's investigation determined that assorted debris, rocks, and chunks of concrete in the excavation backfill generated stress intensification that resulted in a circumferential crack in a plastic pipe at a connection to a plastic fitting. Available documentation indicates that the crack was brittle-like.

A July 1982 natural gas explosion and fire in California destroyed a store and two residences, severely damaged nearby commercial and residential structures, and damaged automobiles [15]. The Safety Board's investigation identified a longitudinal crack in a plastic pipe as the source of the gas leak that led to the explosion. Available documentation indicates that the crack was brittle-like.

A September 1983 natural gas explosion in Minnesota involved the same brand of plastic piping as that involved in the Waterloo and Nebraska accidents [16]. The explosion destroyed one house and damaged several others, and injured five persons. The Safety Board's investigation determined that rock impingement generated stress intensification that resulted in a crack in a plastic pipe. Available documentation indicates that the crack was brittle-like.

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One woman was killed and her 9-month-old daughter injured in a December 1983 natural gas explosion and fire in Texas [17]. The Safety Board's investigation determined that the source of the gas leak was a brittle-like crack that had resulted from damage to the plastic pipe during an earlier squeezing operation to control gas flow [18].

A September 1984 natural gas explosion in Arizona resulted in five fatalities, seven injuries, and two destroyed apartments [19]. The Safety Board's investigation determined that a reaction between a segment of plastic pipe and some liquid trapped in the pipe weakened the pipe and led to a brittle-like crack.

During the course of the investigation of the accident at Waterloo, Iowa, the Safety Board learned of several other accidents, not investigated by the Safety Board, that involved cracks in the same brand of plastic piping as that involved in the Waterloo accident. Three of these accidents, which occurred in Illinois (1978 and 1979) and in Iowa (1983), resulted in five injuries and damage to buildings [20]. A 1995 accident in Michigan also involved a crack in this same brand of pipe [21]. Available documentation indicates that the cracks were brittle-like.

Strength Ratings, Ductility, and Material Standards for Plastic Piping

During the 1950s and early 1960s, when plastic piping was beginning to gain acceptance as an alternative to steel piping for the transport of water and gas, no established procedures existed for rating the strength of materials intended for use in plastic pressure piping.

In November 1958, the Thermoplastic Pipe Division of the Society of the Plastics Industry organized a group called the Working Stress Subcommittee [22]. The subcommittee, in January 1963, issued a procedure (hereinafter referred to as the PPI procedure) that specified a uniform protocol for rating the strength of materials used in the manufacture of thermoplastic pipe in the United States. In March 1963, the Thermoplastic Pipe Division adopted its current name, the Plastics Pipe Institute (PPI).

On July 1, 1963, the PPI established a voluntary program of listing the material strengths of plastic piping materials, specifically, those materials designed for water applications. To apply for a PPI listing, applicants sent strength test data to the PPI, often accompanied by the manufacturer's analysis of the data and a proposed material strength rating. The PPI would analyze the data and, if warranted, list the material for the calculated strength. The PPI did not certify or approve the material received or validate the data submitted, nor did it audit or inspect those submitting data [23].

In simplified terms, the PPI procedure, which is performed by the materials manufacturers themselves, involves recording how much time it takes stressed pipe samples to rupture at a standardized temperature of 73 °F. The stresses used in the tests are recorded as "hoop stress," which is tensile stress in the wall of the

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pipe in a circumferential orientation (hence the term "hoop") due to internal pressure. Although hoop stress is expressed in pounds per square inch, it is a value quite different from the pipe's internal pressure.

The testing process involves subjecting pipe samples to various hoop stress levels, and then recording the time to rupture. For some samples at some pressures, rupture will occur in as little as 10 hours. As hoop stress is reduced, the time-to- failure increases. At some hoop stress level, at least one of the tested specimens will not rupture until at least 10,000 hours (slightly more than 1 year). After the rupture data points (hoop stresses and times-to-failure) for this material have been recorded, the data points are plotted on log-log coordinates as the relationship between hoop stress and time-to-failure. (see Figure 13.3.) A mathematically developed "best-fit" straight line is correlated with the data points to represent the material's resistance to rupturing at various hoop stress levels.

Once the best-fit straight line is calculated to 10,000 hours, it is extrapolated to 100,000 hours (about 11 years). The hoop stress level that coincides with the point at which the line intersects the 100,000-hour time line represents the calculated long-term hydrostatic strength of that particular material.

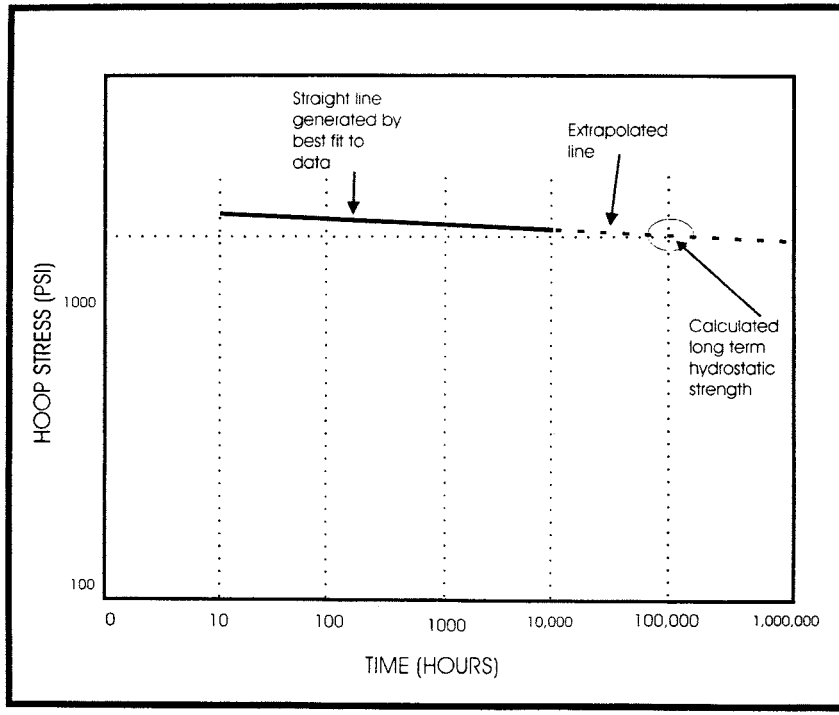

FIGURE 13.3 Stress rupture data plotted as best-fit straight line and extrapolated to determine long-term hydrostatic strength. *(Derived from A.G.A Plastic pipe Manual for Gas Service)*

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To simplify the ratings and facilitate standardization, the PPI procedure grouped materials with similar long-term hydrostatic strength ranges into "hydrostatic design basis" categories. For example, those materials having long-term hydrostatic strengths between 1200 and 1520 psi were grouped together and assigned a hydrostatic design basis of 1250 psi. Those materials having long-term hydrostatic strengths between 1530 and 1910 psi were grouped together and assigned a hydrostatic design basis of 1600 psi.

To help ensure the validity of the mathematically derived line, the PPI procedure required the submission of all rupture data points. It further specified the minimum number of data points and minimum number of tested lots. The procedure employed statistical tests to verify the quality of data and quality of fit to the mathematically derived line. These measures excluded materials when the data demonstrated excessive data scatter due to either inadequate quality of data or deviation from straight line behavior through 10,000 hours [24].

The PPI procedure, after some refinement, was issued as an ASTM method in 1969 (ASTM D2837). The PPI adopted a policy document for PPI's listing service in 1968, which remained under PPI jurisdiction [25].

When polyethylene pipe fails during laboratory stress rupture testing at 73 °F, it fails primarily by means of ductile fractures, which are characterized by substantial visible deformation During stress rupture tests, if hoop stress on the test piping is decreased, the time-to-failure increases, and the amount of deformation apparent in the failure decreases [26]. In pipe subjected to prolonged stress rupture testing, slit fractures may begin 26 Mruk, S. A., "The Ductile Failure of Polyethylene Pipe," SPE Journal, Vol. 19, No. 1, January 1963 [27]. Because of the frequent lack of visible deformation associated with them, slit fractures are also referred to as brittle-like fractures. to appear at some point (depending on the specific polyethylene resin material). The PPI procedure did not differentiate between ductile and slit failure types, and, based on most available laboratory test data (at 73°F), assumed that both types of failures would be described by the same extrapolated (straight) line [28].

In 1963-64, the National Sanitation Foundation amended its standard for plastic piping used for potable water service to require that manufacturers furnish evidence of having an appropriate strength rating in accordance with the PPI procedure [29]. Manufacturers then decided to utilize the PPI listing service, having determined that this was the most convenient way to furnish the required evidence.

In 1966, the ASTM issued ASTM D2513, the society's first standard specification covering polyethylene plastic piping for gas service [30]. ASTM D2513 made reference to long-term hydrostatic strength and hydrostatic design stress and included an appendix defining these terms in accordance with the PPI procedure It also required that polyethylene pipe meet certain requirements of ASTM D2239 (a polyethylene pipe specification for water service), which also included references to the PPI procedure. ASTM D2513 did not explicitly require materials to have a PPI listing [31].

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Even without an explicit requirement, some manufacturers voluntarily obtained PPI listings for their resin materials intended for gas use, and some others, as noted above, obtained PPI listings for their resins that were intended for water use (but were similar to their resins intended for gas service) as a way of meeting National Sanitation Foundation requirements [32,33] .

In 1967, the United States of America Standards Institute B31.8 code, Gas Transmission and Distribution Piping Systems, for the first time recognized the suitability of plastic piping for gas distribution service and included requirements for the pipings' use [34]. The 1966 issuance of ASTM D2513 and the 1967 inclusion of plastic piping within B31.8 cleared the way for the general use of plastic piping for gas distribution [35]. B31.8 included a design equation (see discussion below), and although the code, like the ASTM standard, did not explicitly require a PPI listing, it did require that material used to manufacture plastic pipe establish its long-term hydrostatic strength in accordance with the PPI procedure.

On August 12, 1968, the Natural Gas Pipeline Safety Act was enacted, requiring the DOT to adopt minimum Federal regulations for gas pipelines. In December 1968, the DOT instituted interim Federal regulations by federalizing the State pipeline safety regulations that were in place at the time. The DOT, having concluded that the majority of the States required compliance with the 1968 version of B31.8, adopted that version of the code for the Federal regulations covering those States not yet having their own natural gas pipeline safety regulations.

Most of these Federal interim standards were replaced in November 1970 by 49 Code of Federal Regulations (CFR) 192; however, the interim provisions concerning the design, installation, construction, initial inspection, and initial testing of new pipelines remained in effect until March 1971. At that time, 49 CFR 192 incorporated the design equation for plastic pipe from B31.8 and also required that plastic piping conform to ASTM D2513 [36].

The 1967 version of B31.8 introduced fixed design factors (subsequently incorporated into 49 CFR 192) as a catch-all mechanism to account for various influences on pipe performance and durability [37]. These influences included external loadings, limitations of and imprecision in the PPI procedure, variations in pipe manufacturing, handling and storage effects, temperature fluctuations, and harsh environments [38]. A design equation was used to determine the allowable gas service pipe pressure rating based on the hydrostatic design basis category, pipe dimensions, and design factor [39]. The design basis for plastic pipe thus "Validating the Hydrostatic Design Basis of PE Piping Materials." The design equation (with the current design factor, 0.32) can be found in 49 CFR 192.121, although 192.121 erroneously references the long-term hydrostatic strength instead of the hydrostatic design basis category. RSPA is used internal pressures as a design criterion but did not directly take into account additional stresses that could be generated by external loadings, despite the fact that field failures in plastic piping systems were frequently associated with external loads but were rarely attributable to internal pressure effects alone [40].

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Kulmann and Mruk have reported that no direct basis was established to design for external loads because:

- The industry had no easy means of quantifying external loads and their effects on plastic piping systems [41]
- Many in the industry believed that plastic piping, like steel and copper piping, behaved as a ductile material that would withstand considerable deformation before undergoing damage, thus alleviating and redistributing local stress concentrations that would crack brittle materials such as cast iron. This belief resulted from short-term laboratory tests showing that plastic piping had enormous capacity to deform before rupturing [42]

Because of plastic piping's expected ductile behavior, many manufacturers believed it safe to base their designs on average distributed stress concentrations generated primarily by internal pressure and, within reason, to neglect localized stress concentrations. They believed such stress would be reduced by localized yielding, or deformation. Mruk and Palermo have pointed out that design protocols were predicated on the assumption of such ductile behavior [43].

In contrast, cast iron piping has recognized brittle characteristics. The design basis for cast iron therefore does not assume that localized yielding or deformation will reduce stress intensification. As a result, the design protocol for cast iron includes the quantification and direct input of external loading factors that can generate localized stress intensification [44].

Failures in polyethylene piping that occur under actual service conditions are frequently slit failures; ductile failures are rare [45]. Slit failures in polyethylene, whether occurring during stress rupture testing or under actual service conditions, result from crack initiation and slow crack growth and are similar to brittle cracks in other materials in that they can occur with little or no visible deformation [46].

During the 1960s and 1970s, some experts began to question the validity of the PPI procedure's assumption of a continuing, gradual straight-line decline in strength (Figure 13.3) [47]. By the late 1970s and early 1980s, the plastic piping industry in the United States realized that testing piping materials at elevated temperatures was a way to accelerate failure behavior that would occur much later at lower temperatures (such as 73 °F). Based on data derived from elevated-temperature testing, the industry concluded that the gradual straight-line decline in strength assumed by the PPI procedure was not valid. Instead, two distinct failure zones were indicated for polyethylene piping in stress rupture testing. The first zone is characterized by the gradual straight-line decline in strength accompanied primarily by ductile fractures. The first zone gradually transitions to the second zone, which is characterized by a more rapid decline in strength accompanied by brittle-like fractures only. The time and magnitude of this more rapid decline in strength varies by type and brand of polyethylene. Piping manufacturers have worked to improve their products' resistance to slit-type failures and thus to push this downturn further

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out in time. The PPI procedure did not account for this downturn, and the difference between the actual falloff shown in Figure 13.4 and the projected straight-line strengths shown in figure 13.3 for listed materials became more pronounced as the lines were extrapolated beyond 100,000 hours.

As manufacturers steadily improved their formulations to delay the onset of the downturn in long-term strength and associated brittle-like behavior, PPI and ASTM industry standards were upgraded to reflect what the major manufacturers were able and willing to accomplish [48]. Accordingly, and because a consensus of manufacturers recognized the relationship between improved elevated-temperature properties and improved longer term pipe performance, the PPI in 1982 recommended that ASTM D2513 specify a minimum acceptable hydrostatic strength at 140°F. In 1984, ASTM D2513 included a statement in its non-mandatory appendix that gas pipe materials should have a specified long-term hydrostatic strength at 140°F. In the 1988 edition, this requirement was moved to the mandatory section of the standard. This strength at 140°F was calculated the same way that the 73°F strength was calculated—data demonstrating a straight line to 10,000 hours was assumed to extrapolate to 100,000 hours without a downturn.

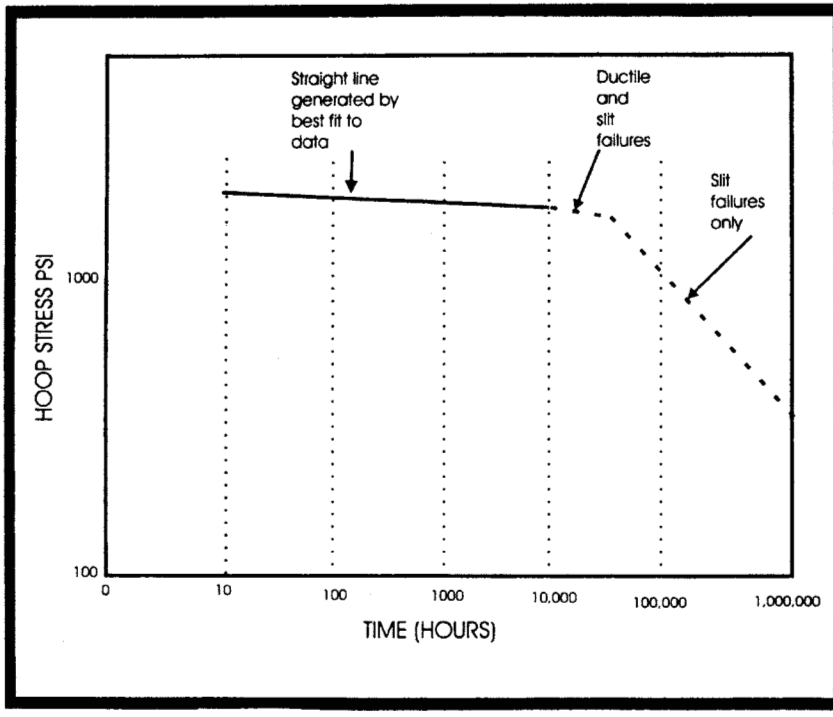

FIGURE 13.4 Stress rupture data plotted as best-fit straight line transitioning to downturn in strength. *(Derived for A.G.A. Plastic Pipe Manual for Gas Service)*

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Gradually, more manufacturers obtained PPI listings for their resins intended for gas service, and by the early to mid-1980s, virtually all resins used for gas service had PPI listings. At that time, a consensus of manufacturers supported a change within ASTM D2513 to require PPI listings. In 1985, ASTM D2513 was revised to require that materials for gas service have a PPI listing.

By 1985, manufacturers reached a consensus to exclude materials that deviated from the 73°F extrapolation before 100,000 hours. The PPI adopted this restriction and advised the industry that, effective January 1986, all materials not demonstrating straight-line performance to 100,000 hours would be dropped from its listing.In 1988, ASTM D2837 also included the restriction [49, 50]. The new PPI and ASTM requirements had no effect on pipe installed prior to the effective date of the requirements.

On August 20, 1997, after manufacturers reached a consensus, the PPI issued notice that, effective January 1999, in order for materials to retain their PPI listings for long-term hydrostatic strength at temperatures above 73°F (for example, at 140°F), these materials will have to demonstrate (mathematically, via elevated-temperature testing) that a downturn does not exist prior to 100,000 hours or, alternatively, if a downturn does exist before 100,000 hours, the strength rating will be reduced to reflect the point at which the calculated downturn in strength intercepts 100,000 hours. An ASTM project has been initiated to incorporate this requirement within ASTM D2837. The Safety Board also notes that the PPI has endorsed a proposal to have ASTM D2513 require polyethylene piping to have no downturn in stress rupture testing at 73°F before 50 years, as mathematically determined in elevated-temperature tests.

All available evidence indicates that polyethylene piping's resistance to brittle-like cracking has improved significantly through the years. Several experts in gas distribution plastic piping have told the Safety Board that a majority of the polyethylene piping manufactured in the 1960s and early 1970s had poor resistance to brittle-like cracking, while only a minority of that manufactured by the early 1980s could be so characterized [51]. Several gas system operators have told the Safety Board that they are aware of no instances of brittle-like cracking with their own modern polyethylene piping installations.

Century Pipe Evaluation and History

The Safety Board's investigation of the Waterloo, Iowa, accident determined that the pipe involved in the accident had been manufactured by Amdevco Products Corporation (Amdevco) in Mankato, Minnesota. Amdevco's Mankato plant first began producing plastic pipe in 1970, with plastic piping for gas service as its only piping product. Amdevco made the pipe from Union Carbide's Bakelite DHDA 2077 Tan 3955 (hereinafter referred to as DHDA 2077 Tan) resin material. Century Utility Products, Inc., marketed the pipe to Iowa Public Service Company, and Century's name was marked on the pipe. Century and Amdevco formally merged in 1973 [52]. The combined corporation went out of business in 1979.

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Because Amdevco/Century no longer exists, Safety Board investigators could locate no records to indicate the qualification steps Amdevco may have performed before Century marketed its pipe to Iowa Public Service Company. A plastic pipe manufacturer would normally have obtained documentation from its resin supplier indicating that the resin material had a sufficient long-term hydrostatic strength. Code B31.8 required and ASTM D2513 recommended that polyethylene pipe manufacturers perform certain quality control tests on production samples, including twice-per- year sustained pressure tests.

Like many gas operators of that time, Iowa Public Service Company (now MidAmerican Energy Corporation), which had installed the Waterloo piping in 1971, had no formal program for testing or evaluating products. According to MidAmerican Energy, the company accepted representations from a principal of Century, a former DuPont employee, who portrayed himself as being intimately involved with the development and marketing of DuPont's polyethylene piping. MidAmerican Energy has reported that these representations included assertions that Century plastic pipe met industry standards and had the same formulation as DuPont's plastic pipe. In 1970, according to MidAmerican Energy officials, Century offered Iowa Public Service Company attractive commercial terms for its product, with the result that, in 1970, when Amdevco first started to manufacture pipe, Iowa Public Service Company began purchasing all of its plastic pipe from Century [53].

Before the Waterloo accident, a previous accident involving Century pipe had been reported in the Midwest Gas (the operator at the time of the accident) system. That accident occurred in August 1983 in Hudson, Iowa, and resulted in multiple injuries. Midwest Gas, attributing this accident to a rock pressing into the pipe, considered it an isolated incident. During 1992-94, the company had two significant failures with pipe fittings involving brittle-like cracks in Century pipe. Sections of the failed pipe were sent to the two affected pipe fitting manufacturers, and one responded that nothing was wrong with the fitting, suggesting instead that the problem might rest with the piping material.

MidAmerican Energy reported that, as a result of these two failures, Midwest Gas directed inquiries to other utilities operating in the Midwest and, in May 1994, learned of one other accident involving Century pipe. In June 1994, Midwest Gas decided to send samples of Century polyethylene piping to an independent laboratory for test and evaluation. The sample collection was in process at the time of the Waterloo accident. In August 1995, Midwest Gas issued a report, based on the laboratory testing, concluding that the Century samples had poor resistance to slow crack growth.

Subsequent to the accident, Midwest Gas worked to determine if its installations with Century plastic piping had had higher rates of failure than those with piping from other manufacturers. After analyzing the data, Midwest Gas concluded that the piping installations with Century piping had failure rates that were significantly higher than those installations with plastic piping from other manufacturers. Based on this analysis, as well as on other factors—including the severity and consequences of leaks involving Century piping, the laboratory

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test results, recommendations from two manufacturers of pipe fittings cautioning against use of their fittings with Century pipe because of the pipe's poor resistance to brittle-like cracking, and interviews with field personnel—MidAmerican Energy (the current operator) has replaced all its known Century piping with new piping, completing the replacement program in 1997.

Safety Board investigators found little additional documentation regarding qualification tests of Century plastic pipe by other gas system operators having Century pipe in service. A reference was found to a 1971 Northern States Power Company Testing Department progress report stating that Century pipe complied with ASTM D2513, and that the pipe was acceptable for use with DuPont polyethylene fittings. The actual progress report and records of any tests that may have been performed were not located [54].

Union Carbide DHDA 2077 Tan Resin. The resin used to manufacture the pipe involved in the Waterloo accident was DHDA 2077 Tan. To examine how Union Carbide qualified this material requires some background.

During the late 1960s, several companies manufactured plastic resin and plastic pipe for the gas distribution plastic piping market. At that time, Union Carbide began a process of modifying its DHDA 2077 Black resin (for water distribution) in order to create a DHDA 2077 Tan resin for the gas distribution industry.

Before Union Carbide could market its DHDA 2077 Tan resin material for natural gas service, it needed to generate stress rupture data, in accordance with the PPI procedure, that would support the long-term hydrostatic strength rating it was assigning to the material (a requirement of the interim Federal regulations effective at that time) [55]. The company had three resources to draw upon to support the hydrostatic design basis category:

1. Internal stress rupture data on its DHDA 2077 Tan resin
2. A PPI listing already obtained on its similar black resin
3. Additional internal stress rupture data on its black resin

On June 11, 1968, Union Carbide began stress rupture testing on specimens of pipe made from a pilot-plant batch of its newly developed DHDA 2077 Tan resin. The results of this testing supported Union Carbide's declared hydrostatic design basis category for DHDA 2077 Tan. The number of data points generated by these stress rupture tests for the DHDA 2077 Tan was less than that required by PPI procedure; however, Union Carbide began to market the product for use in gas systems based on these tests and on additional testing performed on the company's black resin material.

Because Union Carbide had not developed the PPI-prescribed number of data points on its DHDA 2077 Tan resin before marketing the product, Safety Board investigators reviewed the data the company developed on its black resin. A review of Union Carbide's laboratory notebooks revealed that a number of adverse data points Union Carbide developed for its black resin were not submitted to the PPI when the company applied for a PPI listing for the black material [56].

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Union Carbide first made a commercial version of its DHDA 2077 Tan resin during the spring of 1969, and in April 1970, a first shipment of 80,000 pounds of DHDA 2077 Tan resin was shipped to Amdevco's Mankato plant. The next shipment of the material to Amdevco was not until 1971. Based on Amdevco's June 11, 1970, manufacturing date for the Waterloo pipe, Union Carbide manufactured, sold, and delivered the resin used to make the Waterloo pipe between the spring of 1969 and June 11, 1970, and the resin used to make the pipe involved in the Waterloo accident probably was included in the April 1970 shipment.

Union Carbide began, on December 3, 1970, additional stress rupture tests on its commercial DHDA 2077 Tan resin. These tests generated the results to further support its claimed long-term hydrostatic strength and also provided the number of data points required by the PPI procedure. Additional stress rupture tests on the commercial DHDA 2077 Tan resin beginning on December 28, 1970, and again on January 6, 1972, further supported the material's long-term hydrostatic strength.

During the late 1960s and 1970s, Minnegasco, a gas system operator based in Minneapolis, Minnesota, routinely employed a 1,000-hour sustained pressure test at 100°F detailed in ASTM D2239 and a 1,000-hour sustained pressure test at 73°F detailed in ASTM D2513 to qualify plastic piping for use in its system. Minnegasco went beyond the requirements of ASTM standards by continuing both versions of the testing beyond 1,000 hours until eventual failure occurred. The company used this information to evaluate the relative strengths of different brands of piping.

In 1969-70, Minnegasco began a series of tests on samples from five different suppliers of plastic piping made from DHDA 2077 Tan resin. On March 3, 1972, Minnegasco's laboratory issued an internal report that contained the results of its latest tests on piping made from the resin and referenced earlier tests on several brands of piping (including Amdevco/Century) that were also made from it. Based on this report, Minnegasco rejected for use in its gas system the DHDA 2077 Tan resin. According to the report, the company rejected the material because (1) none of the pipe samples made from this resin could consistently pass the 1,000-hour sustained pressure test at 100°F, and (2) the pipe samples had lower performance in 73°F sustained pressure tests than similar plastic piping materials already in use in the company's gas system.

In 1971, Union Carbide acknowledged to a pipe manufacturer that piping material manufactured by DuPont had a higher pressure rating at 100°F than did its own DHDA 2077 Tan. Union Carbide laboratory notebooks examined by the Safety Board showed test results for the DHDA 2077 Tan material that generally met the 1,000-hour sustained pressure test value at both 100°F and 73°F, although, in the case of the 100°F test, not by a wide margin. The notebooks also showed that the material had an early ductile-to-brittle transition point in stress rupture tests [57].

Information Dissemination Within the Gas Industry. The OPS reports that more than 1,200 gas distribution or master meter system pipeline operators submit reports to the OPS [58]. Additionally, more than 9,000 gas distribution or master meter system pipeline operators are subject to oversight by the States.

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As noted earlier, a frequent failure mechanism with polyethylene piping involves crack initiation and slow crack growth. These brittle-like fractures occur at points of stress intensification generated by external loading acting in concert with internal pressure and residual stresses [59].

A 1985 paper analyzed, for linear (straight line) behavior up to 100,000 hours, the stress rupture test performance (by elevated-temperature testing) of six polyethylene piping materials [60]. The results were then correlated with field performance. This paper found that those materials that did not maintain linearity through 100,000 hours had what the author characterized as "known poor" or "questionable" field performance. On the other hand, those materials that maintained linearity through 100,000 hours had what the author characterized as "known good" field performance through their 20-year history logged as of 1985.

By the early to mid-1980s, the industry had developed a method to mathematically relate failure times to temperatures and stresses during stress rupture testing [61]. In the early 1990s, the industry developed "shift functions," another mathematical method to relate failure times to temperatures and stresses [62].

One study pointed out that using mathematical methods to calculate the remaining service life of pipe under the assumption that the pipe would only be exposed to stresses of internal operating pressures would result in unrealistically long service-life predictions [63]. As noted earlier, polyethylene piping systems have failed at points of long-term stress intensification caused by external loading acting in concert with internal pressure and residual stresses; thus, to obtain a realistic prediction of useful service life, stresses from external loadings need to be acknowledged.

Over a number of years, the Gas Research Institute (GRI) sponsored research projects investigating various tests and performance characteristics of polyethylene piping materials. Among these projects was a series of research investigations directed at exploring the fracture mechanics principles behind crack initiation and slow crack growth. These investigations led to the development of slow crack growth tests. The research studies frequently identified the piping and resins studied by codes rather than by specific materials, manufacturers, or dates of manufacture.

In 1984, the GRI published a study that compared and ranked several commercially extruded polyethylene piping materials produced after 1971 [64]. Again, the materials tested were identified by codes. Stress rupture tests were performed using methane and nitrogen as the internal pressure medium and air as the outside environment. Several stress rupture curves showed early transitioning from ductile to brittle failure modes.

The A.G.A.'s Plastic Materials Committee periodically updates the A.G.A Plastic Pipe Manual for Gas Service, which addresses a number of issues covered by this Safety Board special investigation. In 1991, the committee formed a task group to gather and then disseminate to the industry information regarding the performance of older plastic piping systems. The task group disbanded in 1994 without issuing a report.

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In 1982 and 1986, DuPont formally notified its customers about brittle-like cracking concerns with the company's pre-1973 pipe. Safety Board investigators could find no record of either Century/Amdevco, Union Carbide, or any other piping or resin manufacturer formally notifying the gas industry of the susceptibility to premature brittle-like failures of their products. Nor does any mechanism exist to ensure that the OPS receives safety-related information from manufacturers.

Regarding Federal actions on this issue, the OPS has not informed the Safety Board of any substantive action it has taken to advise gas system operators of the susceptibility to premature brittle-like failures of any older polyethylene piping [65].

Installation Standards and Practices

The discussion in this section is intended to present a "snapshot" of the regulations and some of the primary standards, practices, and guidance to prevent stress intensification at plastic service connections to steel tapping tees.

Federal Regulations. The OPS establishes, in 49 CFR 192.361, minimum pipeline safety standards for the installation of gas service piping.

> Paragraph 192.361(b) reads as follows:
>
> *Support and backfill.* Each service line must be properly supported on undisturbed or well-compacted soil….
>
> Paragraph 192.361(d) reads:
>
> *Protection against piping strain and external loading.* Each service line must be installed so as to minimize anticipated piping strain and external loading.

Subsequent to the Waterloo accident, personnel from the Iowa Department of Commerce, after discussions with OPS personnel, stated that the Waterloo installation was not in violation of the Federal regulation. They further stated that, while they agree that the installation of protective sleeves at pipeline connections is prudent, a specific requirement to install protective sleeves is beyond the scope of Part 192 and is inconsistent with the regulation's performance orientation [66].

The Transportation Safety Institute (TSI), part of RSPA, conducts training classes for Federal and State pipeline inspectors. TSI instructors advise class participants that many of the performance-oriented regulations within Part 192 can only be found to be violated if the gas system fails in a way that demonstrates that the regulation was not followed. The TSI acknowledges the difficulty of identifying violations under paragraph 192.361(d). A TSI instructor told the Safety Board that, in the case of the failed pipe at Waterloo, an enforcement action faulting the installation would be unlikely to prevail because of the poor brittle-like crack resistance of the failed pipe and the length of time (23 years) between the installation and failure dates.

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GPTC Guide for Gas Transmission and Distribution Piping Systems. After the adoption of the Natural Gas Pipeline Safety Act in August 1968, the American Society of Mechanical Engineers, after discussions with the Secretary of Transportation, formed the Gas Piping Standards Committee (later renamed the Gas Piping Technology Committee) to develop and publish "how-to" specifications for complying with Federal gas pipeline safety regulations. The result was the GPTC Guide for Gas Transmission and Distribution Piping Systems (GPTC Guide). The GPTC Guide lists the regulations by section number and provides guidance, as appropriate, for each section of the regulation.

In its investigation of the previously referenced 1971 accident in Texas, the Safety Board determined that protective sleeves were too short to fully protect a series of service connections to a main. The Safety Board noted that a protective sleeve must have the correct inner diameter and length if it is to protect the connection from excessive shear forces. As a result, and in response to a Safety Board safety recommendation, the 1974 and later editions of the GPTC Guide included guidance that "a protective sleeve designed for the specific type of connection should be used to reduce stress concentrations" [67]. No guidance was included as to the importance of a protective sleeve's length, diameter, or placement [68].

The GPTC Guide does not include recommendations to limit bending in plastic piping during the installation of service lines under 49 CFR 192.361. Although the guide references the A.G.A. Plastic Pipe Manual for Gas Service, and this manual does provide recommendations on bending limits, the GPTC Guide does not reference this manual in its guidance material under 49 CFR 192.361.

A.G.A. Plastic Pipe Manual for Gas Service. The most recent edition of the *A.G.A. Plastic Pipe Manual for Gas Service* identifies the connection of plastic pipe to service tees as "a critical junction" needing installation measures "to avoid the potentially high…stresses on the plastic at this point" [69]. The manual recommends proper support and the use of protective sleeves. Although the manual recommends following manufacturers' recommendations, no guidance is included on the importance of a protective sleeve's proper length, diameter, or placement. The manual includes, without elaboration, the following sentence:

> *Installation of the tee outlet at angles up to 45° from the vertical or along the axis of the main as a 'side saddle' or 'swing joint' may be considered to further minimize…stresses.*

The 1994 edition adds that manufacturers' recommended limits on bending at fittings may be more restrictive than for a run of piping alone.

A.G.A. Gas Engineering and Operating Practices (GEOP) Series. The preface to the current Distribution Book D-2 of the GEOP series states that the intent of the books is to offer broad general treatment of their subjects, and that listed references provide additional detailed information.

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Figure 13.5 reproduces an illustration from Book D-2. This figure shows a steel tapping tee with a compression coupling joint connected to a plastic service. The illustration shows a protective sleeve and includes a note to extend the protective sleeve to undisturbed or compacted soil or to blocking. But the figure also shows the blocking positioned so that either the edge of the blocking or the edge of the protective sleeve might provide a fixed contact point on the plastic service pipe if the weight of backfill were to cause the pipe to bend down. Additional illustrations within this GEOP series book show this same positioning of the blocking with respect to the plastic pipe.

ASTM. The most recent ASTM standard covering the installation of polyethylene piping was revised in 1994 [70]. This standard addresses the vulnerability of the point-of-service connection to the main.

This standard, advising consultation with manufacturers, recommends taking extra care during bedding and backfilling to provide for firm and uniform support at the point of connection. In addition, the document recommends minimizing bends near tap connections, generally recommending that bends occur no closer than 10 pipe diameters from any fitting and that manufacturers' bend limits be followed. Similar recommendations for avoiding bends close to a fitting can be found in the forward to a water industry standard [71].

This ASTM standard further recommends the use of a protective sleeve if needed to protect against possible differential settlement. Currently, manufacturers that provide protective sleeves have their own criteria for designing sleeve lengths and diameters for their fittings. Some manufacturers' criteria are based on limiting stress to a maximum safe value, while one manufacturer has advised the Safety Board that its sleeve is not designed to limit bending, but only to guard against shear forces at the connection point [72].

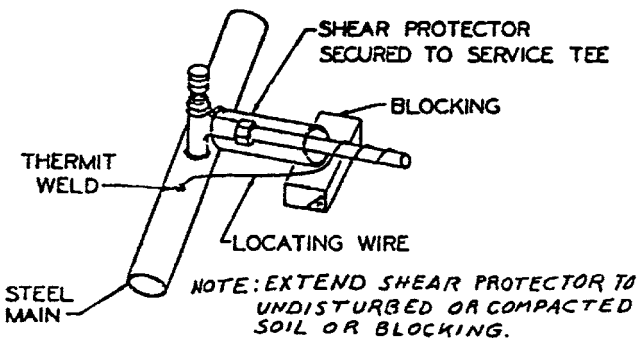

FIGURE 13.5 Reproduction from A.G.A GEOP series illustrating application of protective sleeve. *(Hand-scribed notation from the original)*

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Guidance Manual for Operators of Small Natural Gas Systems. *The OPS/RSPA Guidance Manual for Operators of Small Natural Gas Systems* notes that plastic pipe failures have been found at transitions between plastic and metal pipes at mechanical fittings. The manual states the need to firmly compact soil under plastic pipe, advises following manufacturers' instructions for proper coupling procedures, and shows protective sleeves on connections of plastic services to steel tapping tees. The manual indicates that a properly designed protective sleeve should be used. The manual does not caution against bending the piping in proximity to a connection.

Manufacturers' Recommendations. As noted earlier, both the *A.G.A. Plastic Pipe Manual for Gas Service* and ASTM D2774 specifically refer the reader to manufacturers for further guidance on limiting shear and bending forces at plastic service connections made to steel mains via steel tapping tees.

Bending and Shear Forces. Safety Board investigators contacted representatives of the four principal companies that marketed plastic piping for gas service to determine to what extent plastic piping manufacturers were providing recommendations for limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees. The four manufacturers contacted were CSR PolyPipe, Phillips Driscopipe, Plexco, and Uponor Aldyl Company (Uponor).

Three out of four of these manufacturers had published recommendations addressing these issues. These three manufacturers have historically emphasized heat fusion fitting systems instead of field-assembled mechanical fitting systems [73]. Representatives of these manufacturers indicated that mechanical fittings manufacturers should provide installation instructions covering their systems. Accordingly, one of the manufacturers' published literature referred the reader to the manufacturers of mechanical fittings for installation instructions. Nonetheless, these three major polyethylene pipe manufacturers did, in fact, provide recommendations to limit shear and bending forces, and these recommendations can apply to plastic service connections to steel mains via steel tapping tees.

With respect to the specific issue of limiting bends, DuPont, in January 1970, issued recommendations to limit bends for polyethylene pipe. DuPont/Uponor later published bend radius recommendations that differentiated between pipe segments consisting of pipe alone and those with fusion fittings [74]. The recommendations specified much less bending for pipe segments with fusion fittings; however, DuPont/Uponor did not provide bend limits for mechanical fittings. Two of the other major manufacturers (Phillips Driscopipe and Plexco) provide bend limits and differentiate between pipe alone and pipe with fittings, without specifying the type of fittings. None of the manufacturers' literature discusses bending with or against any residual bend remaining in the pipe after it is uncoiled. (See "Pipe Residual Bending" below.)

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Of these four major polyethylene gas pipe manufacturers, only CSR PolyPipe had no published recommendations for limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees. Although the company does not manufacture steel tapping tees with compression ends for attachment to plastic services, it does manufacture pipe that will be attached to steel tapping tees via mechanical compression couplings. The company has been supplying polyethylene pipe to the gas industry since the 1980s and is thus relatively new to that business compared to the other three major manufacturers [75]. When CSR PolyPipe entered the market, plastic materials were vastly improved compared to earlier versions with respect to resistance to crack initiation and slow crack growth. For this reason, according to CSR PolyPipe personnel, the company saw less need to publish installation recommendations.

The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufactures steel tees with a compression end for plastic gas service connections [76]. The Safety Board identified and contacted representatives of Continental Industries (Continental), Dresser Industries, Inc. (Dresser), Inner-Tite Corp. (Inner-Tite), and Mueller Company (Mueller) [77].

Only Continental and Inner-Tite offered protective sleeves to their customers as an option. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees. On another issue related to protective sleeves, Safety Board examination of a protective sleeve offered by Continental to its customers revealed that the sleeve that did not have sufficient clearance to allow the application of field wrap (intended to protect the steel tee from corrosion after it is in the ground) to that portion of the steel tee under the sleeve. This observation was confirmed by a Continental representative.

Pipe Residual Bending. The service involved in the Waterloo accident was installed with a bend at the connection point to the main. The plastic service pipe leaving the tee immediately curved horizontally. The pipe was cut out and brought into the laboratory, at which time the bend had a measured horizontal radius of approximately 34 inches. Based on field conditions and photos, MidAmerican Energy estimated the original installed horizontal bend radius to have been about 32 inches. This bend is sharper than that allowed by current industry installation recommendations for modern piping adjacent to fittings.

An issue related to recommended bend radius is residual pipe bending. Plastic pipe often arrives at a job site in banded coils. After the bands are released, the coiled pipe will partially straighten, but some residual bending will remain. The water industry already recognizes that bends in the direction of the residual coil bend should be treated differently than bends against the direction of the bend; however, gas industry field bend radius recommendations do not address residual coil bending [78].

A former Iowa Public Service Company employee stated that Iowa Public Service and marketed the complete assembly. Company, in an effort to reduce stress at connection points, generally attempted to install polyethylene services at

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an angle to the main to match the residual bend left after uncoiling the pipe. This former employee stated that no set time was specified to allow for complete relaxing of the pipe, but that the pipe would be placed in the ditch, and the crews would weld the tee at what they judged to be the appropriate angle.

MidAmerican Energy Installation Standards. As a result of the Waterloo accident, Safety Board investigators examined some of MidAmerican Energy's construction standards for minimizing shear and bending forces at plastic service connection points to steel mains. Specifically, Safety Board investigators examined MidAmerican Energy's standards pertaining to providing firm support, using protective sleeves, and limiting bends at plastic service connections to steel mains.

According to the company, MidAmerican Energy no longer installed steel tapping tees with mechanical compression ends to connect to plastic service pipe. Instead, it employed steel tapping tees welded at the factory to factory-made steel-to-plastic transition fittings. It then field-fused the plastic ends from the transition fittings to the plastic service pipe. MidAmerican Energy advised the Safety Board that it had no standard calling for firm compacted support under plastic service connection points to steel mains.

MidAmerican Energy designed, constructed, and installed its own protective sleeves for installation on its purchased steel tapping tee/transition fitting assemblies. MidAmerican Energy required its protective sleeves to be a minimum of 12 inches long; however, MidAmerican Energy could provide no design criteria for this length. MidAmerican Energy has reported that the company's unwritten field practice was to install the smallest diameter sleeve that will clear the field wrapped fitting, but MidAmerican Energy had no written requirements or design criteria for the diameter of its protective sleeves. The company's standard showed the sleeve as approximately centered over the steel-to-plastic transition, and no criteria or instructions were provided for the correct positioning of the sleeves.

The Safety Board notes that manufacturers that provide factory-made steel-to-plastic transition fittings will also provide protective sleeves along with the transition fittings and will provide positioning guidance for their use. Effective January 27, 1997, MidAmerican Energy instituted minimum bend radii requirements that differentiated between pipe segments consisting of pipe alone and pipe with fittings.

Gas System Performance Monitoring

This section examines gas system performance monitoring largely in the context of the Waterloo accident. Federal regulations (49 CFR 192.613 and 192.617) require that gas pipeline system operators have procedures in place for monitoring the performance of their gas systems. These procedures must cover surveillance of gas system failures and leakage history, analysis of failures, submission of failed samples for laboratory examination (to determine the causes of failure), and minimizing the possibility of failure recurrences.

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Prior to the Waterloo accident, Midwest Gas had two systems for tracking, identifying, and statistically characterizing failures. The first system was the leak data base, which tracked the status of leak reports, documented actions taken, and recorded almost all gas system leaks. The data base received input from two primary sources: leak reports from customers and leak survey results. The data base parameters classified the general type of piping material that leaked (such as "plastic," "cast iron," "bare steel"), and indicated whether the leak occurred in pipe or certain fittings. The parameters did not include manufacturers, manufacturing or installation dates, sizes, or failure conditions commonly found with plastic piping (for example, poor fusions, bending force failures, insufficient soil compaction, rock impingement failures, and lack or improper use of protective sleeves) [79]. The data base indicated that the performance of plastic piping overall was comparable to other piping materials. MidAmerican Energy stated that the parameters chosen for this data base were those required for reporting to the DOT. The company said the parameters were also chosen on the premise that pipe meeting industry specifications would perform similarly.

The second system used by Midwest Gas for tracking failures was the company's material failure report data base, which was intended for use in evaluating the quality and performance histories of products installed in the company's gas system. Input to the data base was by way of a form (or, in some cases, a tag) filled out by field personnel. The form included categories such as the manufacturer, size, and an internal material identification number of the affected pipe or component. It also included areas for a narrative description of the failure. The form did not include dates of manufacture or installation dates or failure conditions commonly found on plastic piping. Field personnel sent the failed item, along with the completed form or tag, to engineering personnel, who examined the item and accompanying information to determine the need for corrections. Midwest Gas personnel then transcribed the narrative description of the failure word-for-word into the data base without attempting to determine and categorize causes of failure. Engineering personnel compiled the available data into periodically issued material summary reports. The company said engineering personnel from time to time sorted available data fields to determine trends.

The material failure report data base included only a portion of the leaks in the Midwest Gas system. For example, if Midwest Gas field personnel corrected a leak by replacing an entire line segment without digging up the leaking component (which the company said was a frequent occurrence with bare steel, cast iron, and certain plastic piping that was difficult to join), the material failure report data base system was not used. Also, field personnel were not required to use the reporting system if they determined that the failed item was related to an operating problem, such as excavation damage, rather than to a material problem. Additionally, the company indicated that the system did not enjoy full participation from field personnel.

When, after the Waterloo accident, Midwest Gas attempted to determine if installations with Century plastic piping had higher rates of failure than those with piping from other manufacturers, it found that its material failure report

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data base's incomplete coverage of gas leaks made that data base unsuitable for the purpose. The company decided instead to use the leak data base, which the company believed included almost all leaks. But because the leak data base did not list the manufacturers of plastic piping, Midwest Gas took several months to correlate entries in the leak data base with records showing the manufacturers of plastic piping. Midwest Gas, in 1995, concluded that piping installations with Century piping had failure incidence rates that were significantly higher than the balance of its plastic piping system. The company did not correlate entries with the years of installation. Since the Waterloo accident, the current Waterloo gas system operator, MidAmerican Energy, in addition to replacing all its Century pipe, has added parameters such as piping size, installation date, and pressure to the forms used for input into its leak data base. Also since the accident, MidAmerican Energy has added parameters such as installation date, pressure, and component location and position to its form for input into its material failure report data base. The company has also worked to determine if any other plastic piping manufacturers can be linked to piping with unacceptable performance.

The current (1994) edition of the A.G.A. Plastic Pipe Manual for Gas Service recommends the use and provides a sample of a form for recording information on plastic piping failures. The manual recommends collecting this information and then performing a visual examination or, in some cases, a laboratory analysis, to determine the type and cause of failure.

CONCLUSIONS

1. Plastic pipe extruded by Century Utility Products, Inc., and made from Union Carbide's DHDA 2077 Tan resin has poor resistance to brittle-like cracking under stress intensification, and this characteristic contributed to the Waterloo, Iowa, accident.
2. The procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.
3. Much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.
4. Gas pipeline operators have had insufficient notification that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to brittle-like cracking and therefore may not have implemented adequate pipeline surveillance and replacement programs for their older piping.

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5. Even though the Gas Research Institute has developed a significant amount of data about older plastic piping used for gas service, because the data have been published in codified terms, the information is not sufficiently useful to gas pipeline system operators.
6. Because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.
7. Because MidAmerican Energy Corporation's gas construction standards do not establish well-defined criteria for supporting plastic pipe connections to steel mains or for designing or installing its protective sleeves at these connections, these standards do not ensure that connections will be adequately protected from stress intensification.
8. Before the Waterloo, Iowa, accident, the systems used by Midwest Gas Company for tracking, identifying, and statistically characterizing plastic piping failures did not permit an effective analysis of system failures and leakage history.
9. Before the Waterloo accident, Midwest Gas Company had had an effective surveillance program that tracked and identified the high leakage rates associated with Century Utility Products, Inc., piping when subjected to stress intensification, the company could have implemented a replacement program for the pipe and may have replaced the failed service connection before the accident.
10. MidAmerican Energy Corporation's current systems for tracking, identifying, and statistically characterizing plastic piping failures do not enable an effective analysis of system failures and leakage history.
11. The use of Continental Industries, Inc., tapping tees with the company's protective sleeves may leave the tapping tees susceptible to corrosion because the sleeves do not provide sufficient clearance for the application of field wrap to the metallic steel tapping tee.

RECOMMENDATIONS

As a result of this special investigation, the National Transportation Safety Board makes the following safety recommendations:

To the Research and Special Programs Administration:

Notify pipeline system operators who have installed polyethylene gas piping extruded by Century Utility Products, Inc., from Union Carbide Corporation

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DHDA 2077 Tan resin of the piping's poor brittle-crack resistance. Require these operators to develop a plan to closely monitor the performance of this piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-1)

Determine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that piping marketed by Century Utility Products, Inc.) that remains in use for gas service nationwide. Inform gas system operators of the findings and require them to closely monitor the performance of the older plastic piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-2)

Immediately notify those States and territories with gas pipeline safety programs of the susceptibility to premature brittle-like cracking of much of the plastic piping manufactured from the 1960s through the early 1980s and of the actions that the Research and Special Programs Administration will require of gas system operators to monitor and replace piping that indicates unacceptable performance. (P-98-3)

In cooperation with the manufacturers of products used in the transportation of gases or liquids regulated by the Office of Pipeline Safety, develop a mechanism by which the Office of Pipeline Safety will receive copies of all safety-related notices, bulletins, and other communications regarding any defect, unintended deviation from design specification, or failure to meet expected performance of any piping or piping product that is now in use or that may be expected to be in use for the transport of hazardous materials. (P-98-4)

Revise the *Guidance Manual for Operators of Small Natural Gas Systems* to include more complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should address pipe bending limits and should emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly. (P-98-5)

To the Gas Research Institute:

Publish the codes used to identify plastic piping products in previous Gas Research Institute studies to make the information contained in these studies more useful to pipeline system operators. (P-98-6)

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To the Plastics Pipe Institute:

Advise your members to notify pipeline system operators if any of their piping products, or materials used in the manufacture of piping products, currently in service for natural gas or other hazardous materials indicate poor resistance to brittle-like failure. (P-98-7)

Advise your plastic pipe manufacturing members to develop and publish recommendations for limiting shear and bending forces at plastic service pipe connections to steel mains. (P-98-8) Advise your plastic pipe manufacturing members to revise their pipeline bend radius recommendations as necessary to take into account the effects of residual coil bends in plastic piping. (P-98-9)

To the Gas Piping Technology Committee:

Revise the Guide for Gas Transmission and Distribution Piping Systems to include complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should emphasize the need to limit pipe bending and should include a discussion of the proper design and positioning of a protective sleeve to limit stress at the connection. (P-98-10)

To the American Society for Testing and Materials:

Revise ASTM D2774 to emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly. (P-98-11) Develop and publish standard criteria for the design of protective sleeves to limit stress intensification at plastic pipeline connections. (P-98-12)

To the American Gas Association:

Revise your *Plastic Pipe Manual for Gas Service* and your *Gas Engineering and Operating Practices* series to provide complete and unambiguous guidance for limiting stress at plastic pipe service connections to steel mains. (P-98-13)

To MidAmerican Energy Corporation:

Modify your gas construction standards to require (1) firm compacted support under plastic service connections to steel mains, and (2) the proper design and positioning of protective sleeves at these connections. (P-98-14)

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As a basis for the timely replacement of your plastic piping systems that indicate unacceptable performance, review your existing plastic piping surveillance and analysis program and make the changes necessary to ensure that the program is based on sufficiently precise factors such as piping manufacturer, installation date, pipe diameter, geographical location, and conditions and locations of failures. (P-98-15)

To Continental Industries, Inc.:

Provide a means to ensure that the use of your protective sleeves with your tapping tees at plastic pipe connections to steel mains does not compromise corrosion protection for the connection. (P-98-16)

To Continental Industries, Inc. (P-98-17):

To Dresser Industries, Inc. (P-98-18):

To Inner-Tite Corporation (P-98-19):

To Mueller Company (P-98-20):

Develop and publish recommendations and instructions for limiting shear and bending forces at locations where your steel tapping tees are used to connect plastic service pipe to steel mains.

By the National Transportation Safety Board
James E. Hall
Chairman
Robert T. Francis, II
Vice Chairman
John A. Hammerschmidt
Member
John J. Goglia
Member
George W. Black, Jr.
Member
April 23, 1998

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3. The body of the report will make clear the distinction between brittle-like and ductile fractures.
4. National Transportation Safety Board Pipeline Accident Report—San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996 (NTSB/PAR-97/01).
5. Investigation No. 97-AI-055, October 31, 1997.
6. For more detailed information, see Pipeline Accident Brief in appendix.
7. Uralil, F. S., et al., The Development of Improved Plastic Piping Materials and Systems for Fuel Gas Distribution—Effects of Loads on the Structural and Fracture Behavior of Polyolefin Gas Piping, Gas Research Institute Topical Report, 1/75 - 6/80, NTIS No. PB82- 180654, GRI Report No. 80/0045, 1981, and Hulbert, L. E., Cassady, M. J., Leis, B. N., Skidmore, A., Field Failure Reference Catalog for Polyethylene Gas Piping, Addendum No. 1, Gas Research Institute Report No. 84/0235.2, 1989, and Brown, N. and Lu, X., "Controlling the Quality of PE Gas Piping Systems by Controlling the Quality of the Resin," Proceedings Thirteenth International Plastic Fuel Gas Pipe Symposium, pp. 327-338, American Gas Association, Gas Research Institute, Battelle Columbus Laboratories, 1993.
8. Stress intensification occurs when stress is higher in one area of a pipe than in those areas adjacent to it. Stress intensification can be generated by external forces or a change in the geometry of the pipe (such as at a connection to a fitting).
9. National Transportation Safety Board Pipeline Accident Report—Lone Star Gas Company, Fort Worth, Texas, October 4, 1971 (NTSB/PAR-72/5).
10. National Transportation Safety Board Pipeline The Safety Board's investigation revealed that a brittle-like crack occurred in a plastic pipe as a result of an occluded particle that created a stress point. Accident Report—Washington Gas Light Company, Bowie, Maryland, June 23, 1973 (NTSB/PAR-74/5).
11. National Transportation Safety Board Pipeline Accident Brief—"Natural Gas Corporation, Kinston, North Carolina, September 29, 1975."
12. National Transportation Safety Board Pipeline Accident Brief—"Arizona Public Service Company, Phoenix, Arizona, June 30, 1978."
13. National Transportation Safety Board Pipeline Accident Brief—"Northwestern Public Service, Grand Island, Nebraska, August 28, 1978."
14. National Transportation Safety Board Pipeline Accident Brief—"Southwest Gas Corporation, Tucson, Arizona, December 3, 1981."
15. National Transportation Safety Board Pipeline Accident Brief—"Pacific Gas and Electric Company, San Andreas, California, July 8, 1982."
16. National Transportation Safety Board Pipeline Accident Brief—"Northern States Power Company, Newport, Minnesota, September 19, 1983."
17. National Transportation Safety Board Pipeline Accident Brief—"Lone Star Gas Company, Terell, Texas, December 9, 1983."

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18. Plastic pipe is sometimes squeezed to control the flow of gas. In some cases, squeezing plastic pipe can damage it and make it more susceptible to brittle-like cracking.
19. National Transportation Safety Board Pipeline Accident Report—Arizona Public Service Company Natural Gas Explosion and Fire, Phoenix, Arizona, September 25, 1984 (NTSB/PAR-85/01).
20. Illinois Commerce Commission accident reports dated September 14, 1978, and December 4, 1979. Iowa State Commerce Commission accident report dated August 29, 1983.
21. Research and Special Programs Administration Incident Report—"Gas Distribution System," Report No. 318063, January 8, 1996.
22. This subcommittee was subsequently made into a permanent unit and was renamed the Hydrostatic Stress Board.
23. As a result of Safety Board inquiries to the PPI about its inability to verify the actual data submitted, the institute, in 1997, revised its policy document for its listing service to require a signed statement from applicants that data accompanying applications for a PPI listing are complete, accurate, and reliable.
24. The PPI procedure also had restrictions on the degree of slope of the straight line so that the material's strength would not excessively diminish beyond 100,000 hours.
25. Plastics Pipe Institute, Policies and Procedures for Developing Recommended Hydrostatic Design Stresses for Thermostatic Pipe, PPI-TR3-July 1968.
26. Mruk, S. A., "The Ductile Failure of Polyethylene Pipe," SPE Journal, Vol. 19, No. 1, January 1963.
27. Because of the frequent lack of visible deformation associated with them, slit fractures are also referred to as brittle-like fractures.
28. Kulhman, H. W., Wolter, F., Sowell, S., Smith, R. B., Second Summary Report, The Development of Improved Plastic Pipe for Gas Service, Prepared for the American Gas Association, Battelle Memorial Institute, covering the work from mid-1968 through 1969. Stress rupture tests were performed using methane and nitrogen as the internal pressure medium and air as the outside environment. Some experts have advised the Safety Board that stress rupture testing showing time-to-failure in the slit mode may vary with different pressure media and
29. Now known as NSF International.
30. This standard also included plastic piping materials other than polyethylene.
31. Although adherence to ASTM appendixes is not mandatory, the PPI procedure was the only industry-accepted mechanism to determine long-term hydrostatic strength and hydrostatic design stress.
32. Resins are polymer materials used for the manufacture of plastics.
33. For example, E. I. du Pont de Nemours & Company, Inc., and Union Carbide Corporation.
34. Now known as ASME B31.8.
35. A.G.A. Plastic Pipe Handbook for Gas Service, American Gas Association, Catalog No. X50967, April 1971.
36. RSPA reviews revised editions of ASTM D2513 for acceptability before referencing them in 49 CFR 192.
37. A design factor is similar to a safety factor, except that a design factor attempts to account for other factors not directly included within the design equation that significantly affect the durability of the pipe.
38. Reinhart, F. W., "Whence Cometh the 2.0 Design Factor," Plastics Pipe Institute, undated, and Mruk, S. A.,

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39. The design equation (with the current design factor, 0.32) can be found in 49 CFR 192.121, although 192.121 erroneously references the long-term hydrostatic strength instead of the hydrostatic design basis category. RSPA is currently conducting rule-making activities to correct this error.
40. Kulmann, H. W., Wolter, F., Sowell, S., "Investigation of Joint Performance of Plastic Pipe for Gas Service," 1970 Operating Section Proceedings, American Gas Association, pp. D-191 to D-198.
41. Kulmann, Wolter, and Sowell.
42. Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials."
43. Mruk, S. and Palermo, E., "The Notched Constant Tensile Load Test: A New Index of the Long Term Ductility of Polyethylene Piping Materials," summary of presentation given in the Technical Information Session hosted by ASTM Committee F17's task group on Project 62-95-02, held in conjunction with ASTM Committee F17's November 1996 meetings, New Orleans, LA.
44. Mruk and Palermo and Hunt, W. J., "The Design of Grey and Ductile Cast Iron Pipe," Cast Iron Pipe News, March/April 1970.
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46. Mruk and Palermo have quantified and discussed the deformation in brittle-like failures in: Mruk, S. and Palermo, E., "The Notched Constant Tensile Load Test: A New Index of the Long Term Ductility of Polyethylene Piping Materials," summary of presentation given in the Technical Information Session hosted by ASTM Committee F17's task group on Project 62-95-02, held in conjunction with ASTM Committee F17's November 1996 meetings, New Orleans, LA, and Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials," pp. 202-214, 1985.
47. The 1971 A.G.A. Plastic Handbook for Gas Service noted that the cause and mechanisms of brittle fractures sometimes found with long-term stress rupture testing was not yet well established. Two of the pioneering papers in the United States to suggest a downturn in long-term hydrostatic strength with brittle-like failures or in elevated temperature testing were: Mruk, S. A., "The Ductile Failure of Polyethylene Pipe," SPE Journal, Vol. 19, No. 1, January 1963, and Davis, G. W., "What are Long Term Criteria for Evaluating Plastic Gas Pipe?" Proceedings Third A.G.A. Plastic Pipe Symposium, American Gas Association, pp. 28-35, 1971.
48. Both the PPI and the ASTM work on a consensus principle, meaning that requirements are put into place only when a consensus of voting members is reached. The PPI is a manufacturers' organization. With respect to the ASTM technical committee that generates requirements for plastic piping, the major piping manufacturers participate actively in the committee and are in a position to influence ASTM strength rating requirements.
49. Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials."
50. A.G.A. Plastic Pipe Manual for Gas Service, American Gas Association, Catalog No. XR 9401, 1994.
51. A number of these experts considered material to have poor resistance to brittle-like cracking if the material was shown to have a downturn in strength associated with brittle-like fractures in stress rupture testing (at 73 °F) before 100,000 hours.
52. Because of a series of organizational changes and mergers, the name of the owner/operator of the gas system at Waterloo, Iowa, has changed over the years. In 1971, Iowa Public Service Company installed the gas service that ultimately failed. At the time of the accident, the gas system operator was Midwest Gas Company. The current operator is MidAmerican Energy Corporation.

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53. Iowa Public Service Company continued to purchase DuPont plastic piping fittings until fittings were available from Century. MidAmerican Energy made technical procurement decisions via a Gas Standards Committee. According to company officials, the company has implemented a process to ensure that it continues to receive quality products once the products have passed an initial qualification process.
54. Northern States Power is based in St. Paul, Minnesota.
55. The company was required to follow the PPI procedure in developing the necessary stress rupture data, but no requirement existed for those data to be submitted to the PPI or for the PPI to assign a listing before the tested material could be marketed.
56. Although the PPI procedure required the submission of all valid data points for statistical analysis, the Union Carbide employee who managed the data indicated that he believed he could discard data that, in his judgment, did not adequately characterize the material's performance. Union Carbide has contended that the non-submitted data may have been invalid because of experimental error, uncompleted tests, or other reasons.
57. The data from the laboratory notebooks suggest that this material's early ductile-to-brittle transition would not have met today's standards.
58. Master meter system refers to a pipeline system that distributes gas to a definable area, such as a mobile home park, a housing project, or an apartment complex, where the master meter operator purchases gas for resale to the ultimate consumer.
59. Kanninen, M. F., O'Donoghue, P. E., Popelar, C. F., Popelar, C. H., Kenner, V. H., Brief Guide for the Use of the Slow Crack Growth Test for Modeling and Predicting the Long-Term Performance of Polyethylene Gas Pipes, Gas Research Institute Report 93/0105, February 1993. Because, after extrusion, the outside of the pipe cools before the inside, residual stresses are usually developed in the wall of the pipe.
60. Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials."
61. Bragaw, C. G., "Prediction of Service Life of Polyethylene Gas Piping System," Proceedings Seventh Plastic Fuel Gas Pipe Symposium, pp. 20-24, 1980, and Bragaw, C. G., "Service Rating of Polyethylene Piping Systems by the Rate Process Method," Proceedings Eighth Plastic Fuel Gas Pipe Symposium, pp. 40-47, 1983, and Palermo, E. F., "Rate Process Method as a Practical Approach to a Quality Control Method for Polyethylene Pipe," Proceedings Eighth Plastic Fuel Gas Pipe Symposium, pp. 96-101, 1983, and Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials," and Palermo, E. F., "Rate Process Method Concepts Applied to Hydrostatically Rating Polyethylene Pipe," Proceedings Ninth Plastic Fuel Gas Pipe Symposium, pp. 215-240, 1985.
62. Popelar, C. H., "A Comparison of the Rate Process Method and the Bidirectional Shifting Method," Proceedings of the Thirteenth International Plastic Fuel Gas Pipe Symposium, pp. 151-161, and Henrich, R. C., "Shift Functions," 1992 Operating Section Proceedings, American Gas Association.
63. Broutman, L. J., Bartelt, L. A., Duvall, D. E., Edwards, D. B., Nylander, L. R., Stellmack-Yonan, M., Aging of Plastic Pipe Used for Gas Distribution, Final Report, Gas Research Institute report number GRI-88/ 0285, December 1988.
64. Cassady, M. J., Uralil, F. S., Lustiger, A., Hulbert, L. E., Properties of Polyethylene Gas Piping Materials Topical Report (January 1973 - December 1983), GRI Report 84/0169, Gas Research Institute, Chicago, IL, 1984.
65. The Safety Board asked the OPS for information about its actions in regard to older piping, after which, in 1997, the OPS notified State pipeline safety program managers of several issues regarding Century pipe and solicited input on their experiences with this particular piping.

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66. Protective sleeves are intended to help shield the pipe at the connection point from bearing loads and shear forces and to limit the maximum pipe bending.
67. Safety Recommendation P-72-64 from National Transportation Safety Board Pipeline Accident Report—Lone Star Gas Company, Fort Worth, Texas, October 4, 1971.
68. The correct positioning of the protective sleeve has a bearing on its effective length.
69. A.G.A. Plastic Pipe Manual for Gas Service, American Gas Association, Catalog No. XR 9401, 1994.
70. ASTM D2774-94, Standard Practice for Underground Installation of Thermoplastic Pressure Piping, American Society for Testing and Materials, 1994.
71. Forward to American Water Works Association Standard C901-96, AWWA Standard for Polyethylene (PE) and Tubing, • In. (13 mm) Through 3 In. (76 mm) for Water Service, effective March 1, 1997.
72. Allman, W. B., "Determination of Stresses and Structural Performance in Polyethylene Gas Pipe and Socket Fittings Due to Internal Pressure and External Soil Loads," 1975 Operating Section Proceedings, American Gas Association, 1975.
73. Heat fusion fittings are used to make piping joints by heating the mating surfaces and pressing them together so that they become essentially one piece.
74. Uponor purchased DuPont's plastic pipe business in 1991.
75. CSR Hydro Conduit Company purchased PolyPipe in 1995. PolyPipe began supplying polyethylene pipe to the gas industry in the 1980s.
76. J. B. Rombach, Inc., which manufactures M. B. Skinner Pipeline products, told the Safety Board that it no longer manufactures or markets its "Punch-It-Tee" line of steel tapping tees. Chicago Fittings Corporation told the Safety Board it no longer manufactures or markets its line of steel tapping tees. The Safety Board therefore made no further inquiry with these companies.
77. Inner-Tite did not manufacture steel tees; it purchased them, affixed its own compression connections,
78. Forward to American Water Works Association Standard C901-96.
79. While sizes of the piping, along with a drawing of the piping assembly, were normally written or drawn on the forms, piping size was not captured in the data base generated by these forms.

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